SOLVING EARTH'S MYSTERIES

This line represents the last million years

Cainozoic

Glacial | Post-Glacial
Age of Man | 10000 BC

The length of each line below this represents 100 million years

100 | 60 | 0
Mesozoic | Cainozoic
Cretaceous | Early Tertiary | 25 Late Tertiary
Age of Reptiles | Age of Mammals
Chalk Sea | ALPINE mountain movements

200 | 170 | 100
Late Palæozoic | Mesozoic
Permian | Triassic 145 | Jurassic 120 Cretaceous
Age of Reptiles
sea | sea

300 | 200
Late Palæozoic
Devonian & Old Red Sandstone | Carboniferous | Permian
Age of Fishes | Age of Amphibia
Freshwater | sea | HERCYNIAN mountain movements

400 | 325 | 300
Early Palæozoic | Late Palæozoic
Ordovician | Silurian | Devonian and Old Red Sandstone
Age of Trilobites & Graptolites | Age of Fishes
sea | Caledonian mountain movements

500 | 400
Early Palæozoic
Cambrian | Ordovician
Age of Trilobites
sea | sea

600 | 500
700 | 600
800 | PRECAMBRIAN | 700
900 | 800
1000 | 900

A PANORAMIC SKETCH OF GEOLOGICAL TIME

Solving Earth's Mysteries

OR

Geology for Girls and Boys

By

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*With 181 illustrations in half-tone and line
and a geological map in colour*

BOOK
PRODUCTION
WAR ECONOMY
STANDARD

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PREFACE

MOST boys and girls in their middle teens enjoy hiking. That is one of the pleasures of life. But hiking with the eyes open to the wonders of Nature greatly increases that pleasure. At first it is the little things—a primrose, a squirrel, a breaking wave, a shady rock —that catch the attention; then, afterwards, we begin to gaze upon the large-scale beauty of the landscape as a whole. Now and then we sink to rest on some favourite spot, and sense the calm and peace which communion with Nature brings. At such times it is a good thing occasionally to lift this veil with which Nature so modestly hides her ceaseless activity, her amazing skill, her awe-inspiring patience. At the vision of these qualities sensuous pleasures become caught up into intellectual·delight. The purpose of this book will have been fulfilled when it has helped anyone to lift the veil.

A careful inspection of pictures provides a useful indoor training for tracking the natural processes out of doors and detecting their results. Grateful acknowledgment is due, therefore, to the publishers for their readiness to incorporate an ample supply of pictures. The names of those who have so kindly placed original negatives at my disposal are attached to the pictures. In Figs. 28 and 90, negatives have been used which were given to me long ago, but unfortunately the names of the donors have been lost. I should like here to record my thanks to all these, and especially to Mr Walter Sutcliffe, of University College, Nottingham, who has expended so much time, enthusiasm, and skill upon the photographic side of this work. Certain valuable illustrations have been reproduced from *A Text-book of Geology*, by Professor A. W. Grabau. Their source is in all cases indicated beneath. To the publishers of the work, D. C. Heath and Co., of Boston, U.S.A. considerable thanks are due in this connexion.

<div align="right">H. H. SWINNERTON</div>

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THE SEARCH BEGUN

CHAPTER I

CLUE-HUNTING

CLUES ! Clues ! Your father looks up from doing his crossword puzzle, which has kept him happy for half an hour, and says, " I want a word, here are the clues—it has seven letters, the middle one is *l* and the last is *y*." You look up from reading this book and say, " That's easy ! The word is ' geology.' " Whether you are reading a detective story, going tracking with Scouts, or joining in a treasure hunt with your friends, the source of all the fun is the finding of clues, and the following of them up to other clues until the mystery is solved or the treasure found.

There is one great mystery which has interested men everywhere down through the centuries, and that is the mystery of the earth's origin. How did this world come to be ? These rocks and mountains, these rivers and seas, these flowers, birds, boys, girls—whence did they all come ?

The earliest answers to these questions of which we have any knowledge were inscribed in curious writing on clay tablets by learned men who lived three thousand years or more ago in Mesopotamia (Fig. 1). These tell, in story form, how everything we see in Nature around us was the handiwork of an amazing variety of gods, devils, and demons—ugly, gargoyle-like creatures similar to those in the picture (Fig. 2). These stories were long since forgotten, and the tablets lay buried until they were unearthed less than a century ago.

About five centuries before Christ a quite different explanation was given by the Hebrews in the form of a charming poetic story starting with the words, " In the beginning God created the heaven and the earth." This story was kept fresh in the memory and passed on from one generation to another ; and then, a century and a half ago, people began to feel that they would like to know more details about the ways in which rocks and living things were made.

Among those who wanted to know was Charles Lyell (Fig. 3), a student at Oxford University, who, though he was preparing to

become a lawyer, turned aside from his studies to attend lectures on geology by Professor Buckland.   From time to time he spent his holidays on his father's estate in Forfarshire.   In the little lakes

Fig 1   A CLAY TABLET FROM MESOPOTAMIA
This contains a portion of an ancient legend of creation written nearly
three thousand years ago
British Museum

which are scattered about that countryside he found quantities of a small plant called stonewort, or **Chara** (Fig. 4).   This plant has the habit of covering itself with a coating of lime, which it extracts from the water.   When the plants die down in the winter this limy coating

falls on the floor of the lake. Year after year this process is repeated, and thus the lime accumulates. In it are buried the shells of water-snails and the bones of animals that have been drowned. When he was about the age of twenty-six Lyell was on a visit to the estate and found that workmen had drained one of the lakes in order to dig out the lime or marl for local farmers to use for liming or marling their

FIG 2   A BABYLONIAN DEMON, REPRESENTED IN TERRACOTTA
British Museum

land. He was astonished to find that the marl had accumulated to a depth of no less than sixteen feet, and that it had become a genuine limestone as hard as any he had seen quarried for use in building in other parts of the world. Lyell was greatly excited, for now he had found a clue ! He had found out that limestone was actually being formed by plants, animals, and processes working while he himself was alive.

All this may seem to be ordinary common sense to you and me,

but to people of Lyell's day it was a startling discovery that rocks were being made before their eyes, and made in ways that they could see and watch if only they looked. They argued that if limestone is being formed to-day we may hope to discover how sandstone and granite and other rocks are being formed. Lyell devoted the whole of his time to hunting for clues, and since his day many others have followed his example. Multitudes of clues have been found, and

FIG. 3.   SIR CHARLES LYELL
From Grabau's " A Text-book of Geology,"
Part I

many mysteries have been solved, but many more remain to be solved even now.

In detective stories and treasure hunts the finding of one clue leads to the discovery of another. Now, we have seen that Lyell was put on the track of his discovery by workmen. Those workmen were for him a happy accident, for usually when we go hunting for clues we find no one there to help us. Nevertheless, there is always something there to give us hints. That something is the rock itself. For instance, that limestone had in it the shells of pond snails (Fig. 5). Those shells are a clue, for they tell us more about the limestone than that it was partly made of shells. Such snails live only in fresh water. Their presence in the stone tells us, therefore, that it was formed not merely in water but in fresh, not sea, water.

There are, of course, many kinds of limestone (Fig. 6). One of these consists largely of corals. Now, we know that corals live only

in the salt water of warm tropical seas. Those corals, therefore, give us a clue to the birthplace of that limestone.

Thus, by looking carefully at rocks and stones and thinking
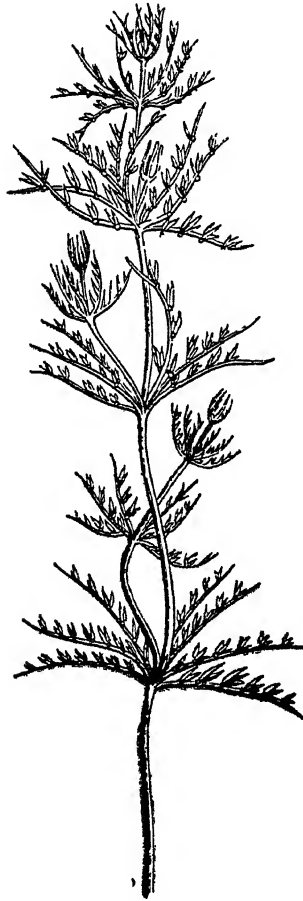
FIG. 4. STONEWORT (CHARA)
This little plant lives in fresh water. It extracts lime from the water, and when it dies it leaves this behind as a fine powder on the bottom of the pond or canal.
From Grabau's, " A Text-book of Geology," Part I

about what we see we find clues which will help us to solve the mystery of how, when, and where they were made. No sooner do we solve one mystery than another comes into view, and we are enticed on to unravel, bit by bit, the wonderful story of the earth. That is the aim and purpose of the science of geology.
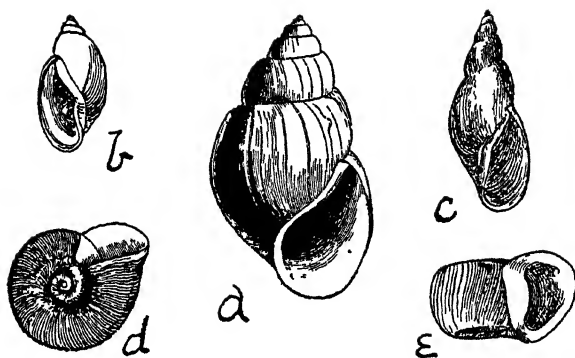
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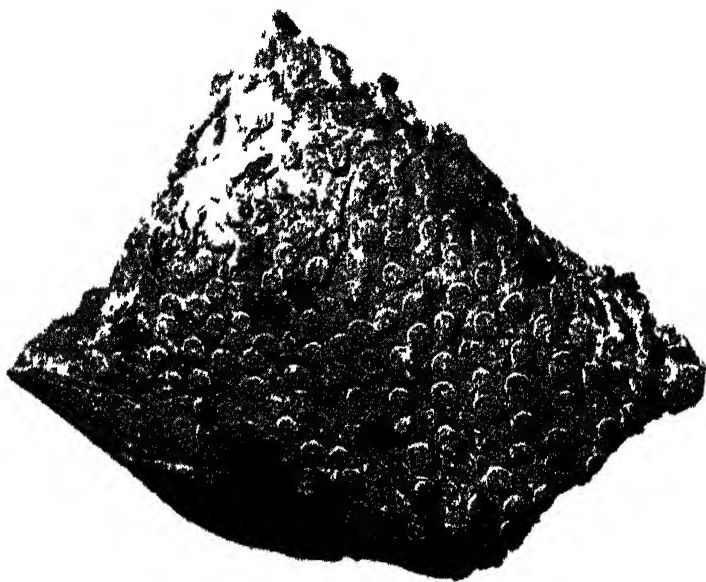
THE ABC OF ROCKS

BREAK up any word on this page and you will find that it is made up of letters. Though there is an endless variety of words, there are only twenty-six letters. Learn these few letters and you will become able to spell or describe any word. So is it with rocks. Though there are many rocks, they are made up of only a few substances. Get to know these and you will soon feel at home when talking about rocks. Now, geology is an outdoor science, but a little careful experimenting with rocks indoors is a great help to a fuller understanding of what is seen in the field.

When you see the word ' rock ' you at once think of blocks of limestone and sandstone, because they are hard and can be broken only by sharp blows with something heavy—the geologist's hammer, for instance. You don't think of clay as a rock, because it is so soft that it can be cut with a knife or squeezed into any shape between the fingers. But geologists call clay a rock—why ? In England it underlies hundreds of square miles of the countryside, and forms the foundations upon which towns and cities such as Bedford, Oxford, and even London are built. Moreover, clay is only soft when it is moist or wet ; when it is dry it is so hard that only a strong hammer-blow will break it. There are, then, quite good reasons for speaking of clay as a rock.

Take a piece of dry clay and crush it gently with a hammer or scrape it with a pocket-knife, and it becomes reduced to a fine powder, so fine that if you blow it gently away it goes as a cloud of dust. That is what clay is made of—**dust.** Mud is only wet dust.

Clay is not the only rock that is made of dust. It may be that where you live there is no clay, but there may be marl or shale or slate. These are all much harder than clay, but they also, when crushed or scraped, become dust. They are all varieties of clay which, under great pressure and with the passage of time, have become hardened. They are all, therefore, classed together as clay rocks, or **argillaceous** rocks (Fig. 7).

Sandstones are usually strong and hard. For that reason they have always been useful for building walls and houses. Some sandstones that split into slabs are called flagstone, and are used for

paving footpaths and courtyards.   But not all sandstones are strong
and hard.   In the heart of the city of Nottingham a great rock stands
up like a precipice.   It looks hard, and yet it is so soft and weak
that lumps of it can be easily broken into pieces by hand and crushed
into loose sand between the fingers.   Indeed, in Anglo-Saxon and

FIG. 7.   THREE KINDS OF ROCK   CONGLOMERATE, SANDSTONE, CLAY
In the conglomerate, note the rounded pebbles imbedded in a fine-grained ground mass, or matrix,
sandstone is shown also in Fig 8 , clay consists of very fine, compressed dust, and therefore the
individual particles are not visible to the eye.
By courtesy of W Sutcliffe, Esq

later times in Nottinghamshire and other parts of England where
the same rock is found people often made dwellings for themselves
by digging caves out of the face of the rock.   In later centuries,
when they lived in proper houses and had the custom of sprinkling
their floors with sand, they got the sand by digging it out of their
underground cellars.   Thus they killed two birds with one stone :

they got sand for domestic use and at the same time enlarged their cellars.

If we take a small quantity of the sand and look at it through a magnifying glass we see that the grains look like tiny pebbles. Many of them have their edges and angles rounded off, and some are almost as round as a ball. You can easily make a collection of these round grains if you put a small quantity of sand near one end of a long strip of stiff paper or thin cardboard. Bend the long edges of the paper slightly upward, then lift the end on which the sand has been placed until the whole is tilted. Now tap the paper gently with a pencil. Every now and then a grain will break loose from the heap and roll rapidly down the slope on to the table. These are the very round grains. Meanwhile the heap of sand will lengthen down the slope with the larger grains gathering at the lower end, because they can travel more quickly, and leaving the smallest grains behind at the upper end. This all shows that sand grains differ in size as well as in shape.

In some sandstones most of the grains are very small ; in others they are of medium size, or they are large and include some as much as one-tenth of an inch in diameter. Such sandstones are described as ' fine-grained,' ' medium-grained,' or ' coarse-grained ' respectively. In some coarse-grained sandstones the grains have not had their edges rounded off. Such a stone is called a **grit**. As already seen, sandstones differ in hardness. Among them the hardest is one called **quartzite**. All these rocks are classed together as sand rocks, or **arenaceous** rocks.

Much less abundant than clays and sandstones are some which are popularly known as pudding-stones, because they have pebbles in them that make them look like a pudding with raisins in it. In some cases the pebbles are angular with sharp edges and corners. In others they are rounded, and may be very round. The first kind is called a **breccia**, the second a **conglomerate**. These are classed as gravelly, or **rudaceous**, rocks.

In some rocks the pebbles consist of limestone or the grains of tiny fragments of coral and shell. More often the grains are as fine as dust. Their texture may, therefore, be that of either conglomerate, sandstone, or clay. They differ from these rocks, however, in that when a drop of weak hydrochloric acid is put upon them numerous bubbles of carbonic-acid gas are formed. This shows that they consist largely of calcium carbonate. Such rocks are called **calcareous** rocks.

THIRSTY ROCKS

IF a dozen pebbles are packed together as closely as possible upon a table it will be found that, because they are rounded, quite large spaces are left between them. The total volume of these spaces
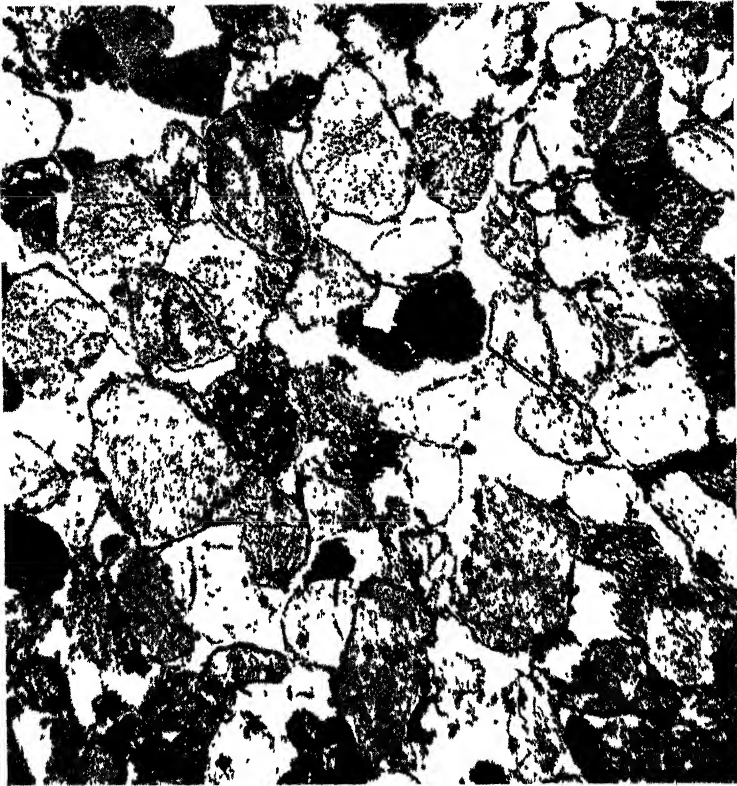
FIG. 8. A THIN SLICE OF BUNTER SANDSTONE

This is how it looks when seen through a microscope. Note the pebble-like grains, some rounded, others more or less angular. Each grain has a thin coating of powdery iron oxide (p. 102). Between the grains there are small spaces called pores (p. 23).

By courtesy of W. Sutcliffe, Esq.

can easily be measured by doing a simple experiment. Take two jam-jars of equal size. Fill one with water and the other with small pebbles. Now pour water from the first into the second

until the pebbles are covered. The volume of water poured out of the one gives the amount of space between the pebbles in the other. Similarly, because the grains in a sandstone are rounded they have spaces between them, no matter how closely they may be packed (Fig. 8). These small spaces are called **pores**. Here again the porosity or capacity of the pores can be measured in the same way. Fill a jar half full with medium-grained or coarse sand. Put the
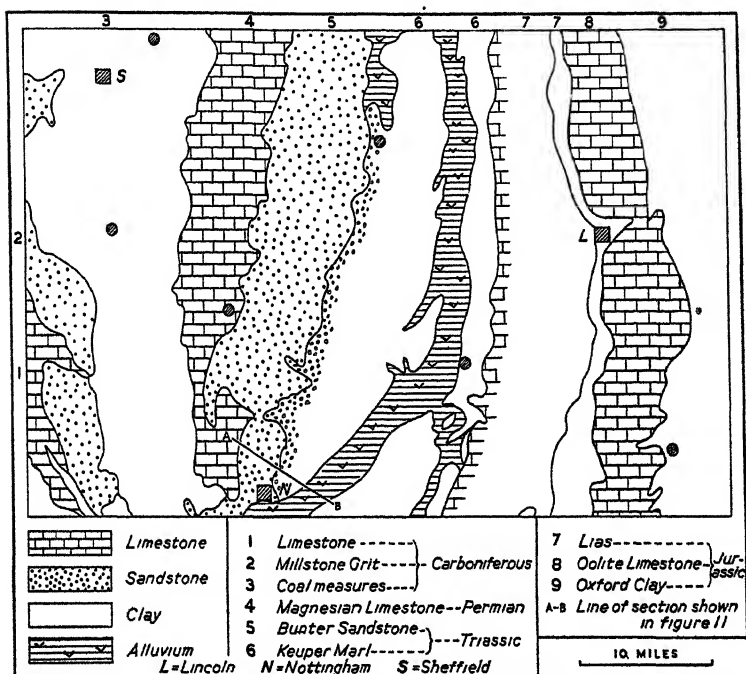
FIG. 9. MAP OF ROCKS WHICH UNDERLIE THE NORTH MIDLANDS

same volume of water into the other jar and mark the level with a strip of paper. Now pour the water slowly on to the sand, giving it time to soak in, until the water begins to show at the top. It will then be seen that sand also can hold quite a large proportion of its own volume of water.

There are many square miles of the countryside which have a foundation of gravel, and many hundreds of square miles which are made up of sandstone (Fig. 9). When rain falls in those areas much of the water soaks through the soil into the gravel and sandstone beneath, and is sucked up by the rock as though it were

thirsty. The soil which covers the ground is therefore
and on that account may not be particularly fertile.

Now, though gravel and sand take up a lot of water,
with it quite easily. Easy come, easy go. You can pro\
tilting the two jars containing pebbles or sand, and you
that the water flows out quite freely. But clay behaves
ferently. To prove this pour a teaspoonful of water into
then cut a block of dry clay about the size and shape of a c
and stand this in the water. After a while you will fin(
water has all gone, for it has been sucked up by the dr\
you go on repeating the experiment patiently the whole
become damp.

In spite of the fact that the clay looks quite com
evidently porous, and can absorb an appreciable quantity
Unlike the sandstone, however, clay keeps a firm hold on
in its pores so that, even when these are full, the water wi
out. If none can flow out then none can flow in, and cor
there can be no free flow of water through the clay.

It has already been noted that vast areas of the cc
founded on clay. This clay is always damp, and so, whe
falls, instead of soaking in it stands about on the surfac
or runs off along innumerable runnels, which cease runnir
up almost as soon as the rain stops. From all this it
understand why in rainy regions there are so many 1
streams on clay lands and so few on sandy and grav
(Fig. 10).

⤫ Rocks through which water flows are said to be **perviou**
like clay through which water does not flow are said to be **im**

Frequently in the countryside the higher ground c
sandstone seated on a floor of clay (Fig. 12). The rain
the sandstone and gradually fills up all the pores in the lo\
which are then said to be saturated. The boundary
the saturated and the unsaturated sandstone is called t
table.

Because the clay is impervious the water cannot sink
sandstone through this floor, but it can flow sideways t
where this crops out to the surface of the ground (Fig. 1.
the water escapes in the form of springs. The water th
the sandstone is replaced by the next lot of rain whicl
from above. The surface of the high ground, being well
level of the water-table, is dry and has no springs. Ne
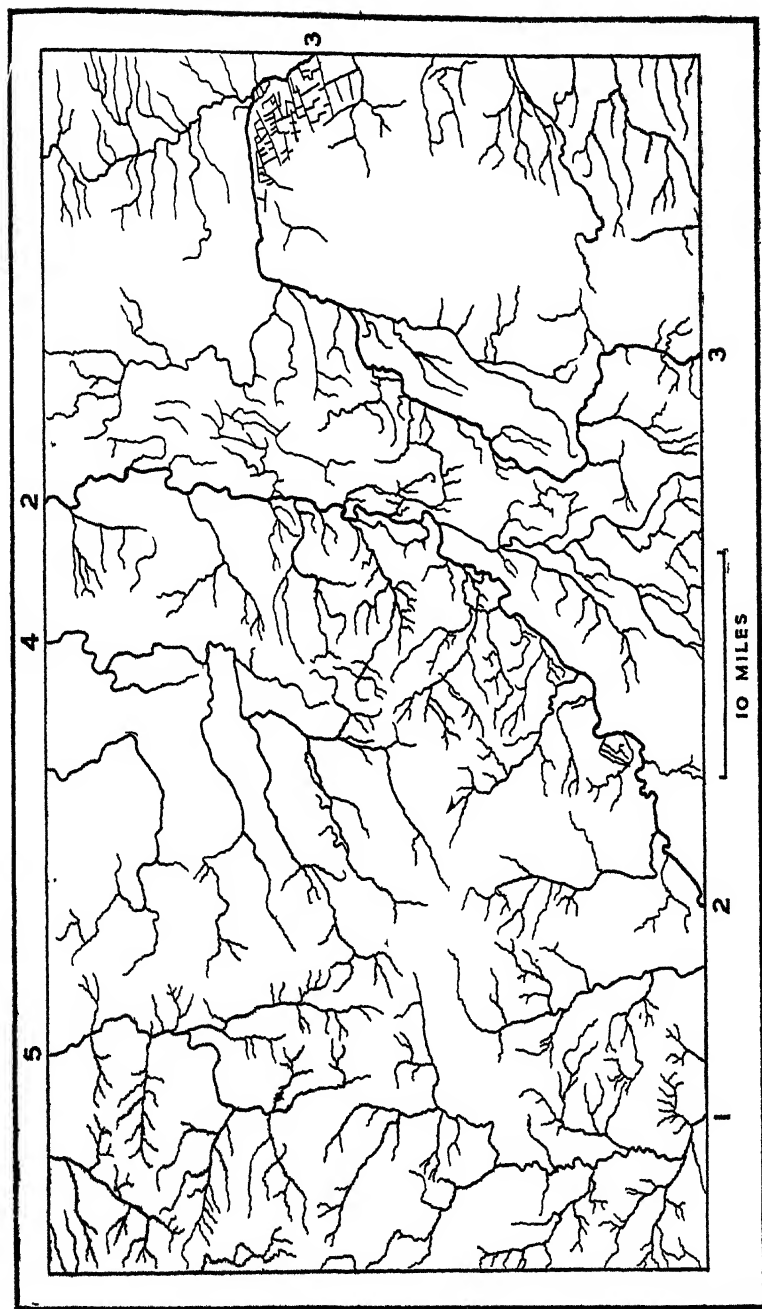
FIG. 10 RIVER MAP OF THE NORTH MIDLANDS

1, Derwent, 2, Trent; 3, Witham, 4, Idle, 5, Rather. Compare the distribution of streams with that of the rocks in Fig. 9, which cover the same area.

even there a supply of water can be got by digging a well down through the dry into the wet rock. From the latter the water flows into and fills the well up to the level of the water-table. Some cities, favourably placed like Nottingham, dig great wells 150 feet or more in depth. With the aid of powerful pumps they draw from these as much as two or even three millions of gallons of water per day. As long as the rain continues to come and
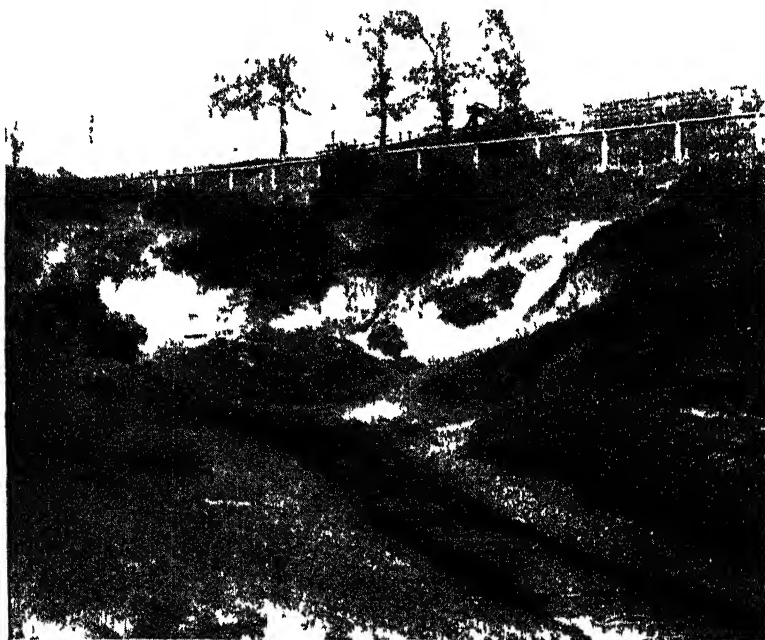
FIG. 11. BULWELL SPRING, NOTTINGHAM

The whole of the ground from the skyline down to the stream is made up of sandstone holding a large reserve of water. This rock can be seen in the small cliff. It rests on an impervious floor of clay. Water is seen flowing out of the sandstone copiously just above the impervious floor.

Photo H. H. Swinnerton

replenish the underground reservoir the supply of water will never fail.

Some rocks, like granite and limestone, are almost non-porous. Where they occur in large masses they are not quite completely solid, for they contain many cracks, some known as **joints** and others as **bedding-planes**. These cracks also become filled with water, but usually the amount is small. This, however, is not the case with limestone, for the water, as it flows into and through the cracks, slowly dissolves the rock, widening the joints and deepening
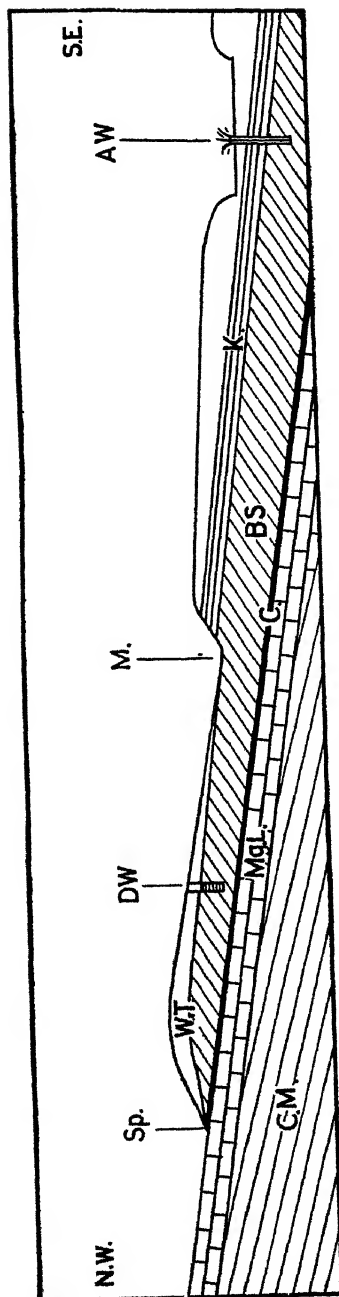
FIG. 12. A GEOLOGICAL SECTION ALONG THE LINE AB IN FIG 9

Rocks· C M , coal-measures ; Mg.L , magnesian limestone , C , thin bed of clay overlying the limestone , B S , bunter sandstone , K , Keuper. Other eferences A.W , Artesian well , D.W , deep well , M , marsh, situated where the water-table comes to the surface   Sp , spring (shown in Fig 11), W.T , water-table

the bedding-planes (Fig. 13). This process goes on contin
at the points the water flows most freely, converts the
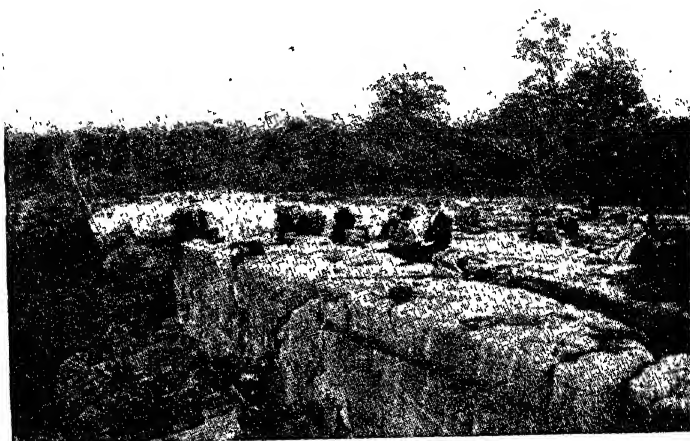
FIG. 13. LIMESTONE SHOWING THE JOINTS WIDENED
FISSURES BY THE SOLVENT ACTION OF RAINWATEI
From Grabau's " A Text-book of Geology," Part II
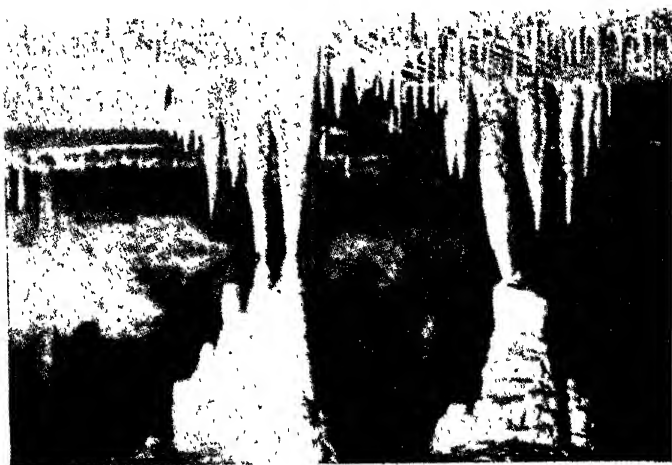
FIG. 14. STALACTITES AND STALAGMITES
Drops of water hanging from the roof of the cave leave behind some of the
when they fall. On reaching the floor, they deposit some more of their lime be:
Thus stalactites are built down from the roof and stalagmites up from the floor.
unite and form pillars.
From Grabau's " A Text-book of Geology," Part I

cracks into underground passage-ways and caves (Fig.
or boring sunk into limestone may, therefore, enter (

subterranean streams or pools, and thus become a valuable source for the supply of water.

In regions where the prevalence of clays and other impervious rocks prevents man from gaining a supply of water from underground he turns his attention to the surface streams. By building a dam across some secluded valley he captures the excess of water which occurs in times of heavy rainfall. The flood waters held back by the dam fill the valley, and thus an artificial lake, or reservoir, is made. But not every out-of-the-way valley is suitable for this
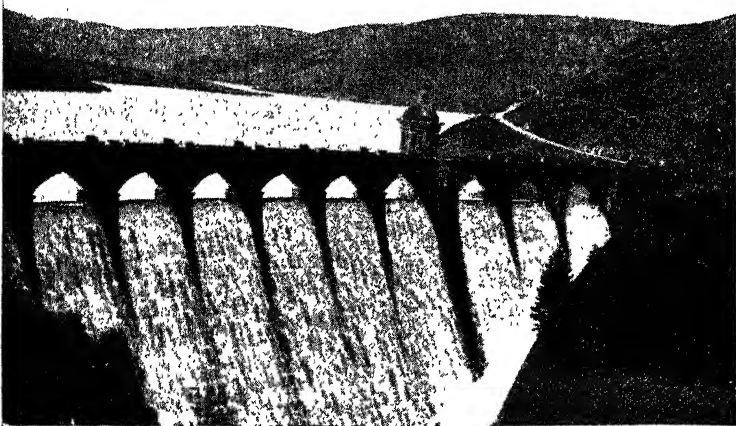
FIG. 15. THE RESERVOIR OF THE BIRMINGHAM WATERWORKS, NEAR RHAYADER
The water is being held up by a great dam which has been built across the valley.
Photo H. H. Swinnerton

purpose, for if the underlying rock happens to be sandstone much of the impounded water could soak away through the ground (Fig. 15). He is careful, therefore, to select a valley where the foundation rock is clay or slate or some other equally impervious rock. Such rocks, therefore, also play an important part in solving the problem of supplying water to large sections of the population.

Thus by looking carefully at sandstone and clay, and doing experiments with them, you have found clues that solve part of the mystery as to what happens to the water when rain falls. You have also seen that by solving such mysteries man has gained much help in supplying his needs.

CHAPTER IV

WHERE DOES SOIL COME FROM?

THAT is a question that very few people stop to ask themselves, because they take soil for granted. But taking things for granted solves no mysteries. Now, farmers and gardeners talk about heavy soils and light soils. When you ask them to show you samples you find that a heavy soil is soft and can be squeezed into shapes. In fact, it behaves like clay. On the other hand a piece of light soil, when squeezed between the fingers, breaks down into fine or coarse sand, and behaves like a soft sandstone. If you dig a hole in the ground through the soil you will find clay rock under the heavy soil and sand rock under the light soil. Soil, then, comes mainly from the rocks beneath. But how are those rocks turned into soil?

Sometimes when the farmer is ploughing his fields in the autumn the plough turns up lumps of clay from beneath. Indeed, the soil itself when turned over forms what look like long ridges of clay. You visit the same field in spring and lo! the ridges have disappeared, and the clay has been broken down into a powdery soil. The farmer looks pleased and says, " We have been having a lot of frosts this winter," and you wonder what frost has got to do with the change.

When there is a hard frost the pools and ponds are frozen over, and you find that water left out of doors in buckets and jam-jars has also been turned to ice. Quite often the jam-jar has been cracked—as we say, " by the frost." The reason for this is that when water freezes it expands and, pressing against the sides of the jar, breaks it. Now clay forming the ridges in the ploughed field is moist ; its pores are full of water. During the frost this water freezes to a depth of a quarter or half an inch, and by expanding cracks up the surfaces of the clods. When the thaw comes the loose fragments fall off the clod and leave fresh surfaces which in turn freeze and thaw ; and so the process is repeated until the whole is reduced almost to a powder. That is how clay provides a basis for soil.

In the same way frost smashes up sandstone and other rocks. Even in a city you will see that the bricks and stones in walls, and

gravestones in cemeteries, have been chipped, or their surfa
powdered until the carving has become faint. Here again w;
that has soaked into the pores has frozen and expanded, and ir
doing has loosened bits of the surface from the block. Frost wc
in just the same way in nature. In mountainous areas, where
surface of the rock is steep or even precipitous, the chips that
broken off slide or fall to the bottom and there become piled up i
great heaps of loose, angular stones called screes. In low-l;
country, where the surface is almost level, the broken fragm;
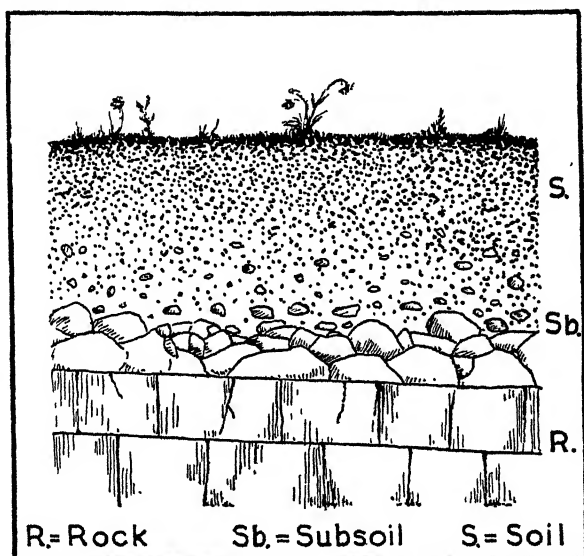
FIG. 16. THE RELATION OF SOIL TO ROCK

stay near the spot where they were broken off, and so the
becomes hidden under a covering of loose stones (Fig. 16).
top stones lie exposed to frost, thaw, and rain, and are gradi
reduced to powder. This powdered stone forms the basis of
While soil may consist entirely of rock waste, the top few in
usually contain a quantity of rotting vegetable matter, or **hun**
The presence of this adds greatly to the fertility of the soil.
layer of broken stones beneath make up what is called **subsoil.**

In countries where there is very little rain the rocks are dry
have no water in their pores to become frozen. Nevertheless, t
rocks also may be smashed and powdered, not by frost, bu
extreme changes of temperature. During the day the suns

pours down upon the outside of the rock and makes it very hot so that it expands with the heat. During the night all that heat escapes, and the outside of the rock becomes cold and contracts. By alternately expanding and contracting the outside layer of the rock struggles to tear itself away from the inside, which is not much affected by the heat of day or the cold of night, and eventually it breaks off, sometimes with explosive violence (Fig. 17). Thus a new surface is left which in turn is shattered and destroyed. In hilly country the loose stones tumble to the bottom of the slopes; but in level country they lie littered about on the ground, where

Fig 17   WEATHERING OF DOLERITE, PONDOLAND
These masses of rock have been rounded by the action of extreme changes of temperature.
By courtesy of G Sneesby, Esq

again those which lie on top are gradually reduced to powder by extreme changes of temperature.

There is yet another way in which rocks are shattered and reduced to dust. You see this other process at work when gardening-tools left out of doors go rusty, when the wires which you have put up to support your raspberry-canes get so rusty that the rust scales off and the wire becomes too thin to be of real use. Water and air, attacking such a resistant material as iron by chemical means, gradually break it down. These agencies attack even the hardest rocks by similar means. They penetrate—it may be only a fraction of an inch—into the substance of the rock, and bring about chemical

changes which cause the thin surface layer to crumble or to peel off, and thus leave a fresh surface exposed to attack.

All these agents—frost, heat, air, water—attack rocks only from the outside. Now, if you think of a square block of rock you will see that a cubic inch situated near the middle of one face of the block has only one square inch of surface exposed to attack ; another situated at the edge exposes two square inches ; a third situated at the corner exposes three square inches. Naturally, therefore, the corners of the block will be destroyed more rapidly than the edges, and the edges more rapidly than the sides. Thus it comes about that in the process of destruction blocks of stone tend to become round.

WHERE DOES SOIL GO TO?

NOTHING looks more quiet and still than the soil with its garment of grasses and flowers ; and yet it is always on the move, or rather is being moved. Of course, gardeners and farmers are always turning the soil over, but they are not the only disturbers of the soil. On almost any patch of grass there may be seen tiny heaps of soil about one inch high. These are called worm-castings. As a worm burrows through the ground it swallows a lot of soil, for this contains food. Later it comes to the surface and ejects the soil once more and so forms one of those little heaps. Darwin, a world-famous naturalist of the nineteenth century, in a very interesting book he wrote about earthworms, tells of an experiment he tried. He scattered a thin layer of chalk over the surface of part of a pasture. Months and years passed by and the chalk gradually became covered by worm-castings and disappeared from sight completely. After waiting patiently for twenty-nine years he dug a shallow trench across the field and found the chalk buried under seven inches of soil. From this, and many other experiments and observations, he showed that every year worms bring to the surface amounts of soil varying from seven and a half to eighteen tons per acre, according to local conditions. There are, of course, many other creatures that share in this work of turning the soil over—rabbits, moles, ants, bees.

Sometimes, when our city streets and pavements get dirty and dusty, there comes a heavy downpour of rain which washes them clean. The water as it runs into the gutters is seen to be quite muddy. Precisely the same process is going on all over the countryside. The drops of rain as they strike the ground loosen particles of soil and run off with them down the slope. Sooner or later the water dries up or soaks into the ground and leaves its little load of soil behind. This is repeated, whenever a shower of rain falls, year in year out. The soil thus carried down the slope is called **rain-wash.**

Often in summer-time, when there has been no rain for weeks, the soil, becoming very dry, shrinks, and is broken by cracks. When at last the rain comes again the soil becomes moist, and by swelling

closes the cracks once more. Thus the soil is continually contract-
ing and expanding. Where the ground is sloping it naturally tends
to contract and expand downhill, with the result that it creeps slowly
down the slope. This movement is so slow that you do not notice
it any more than you notice the hands of a clock moving when you
glance up to see the time. Out in the country you may often have
noticed that where a tree is growing in a sloping field its base is
hidden by the soil on the upper side, but its roots lie exposed to
view below (Fig. 18). To the right and left of the tree, however,
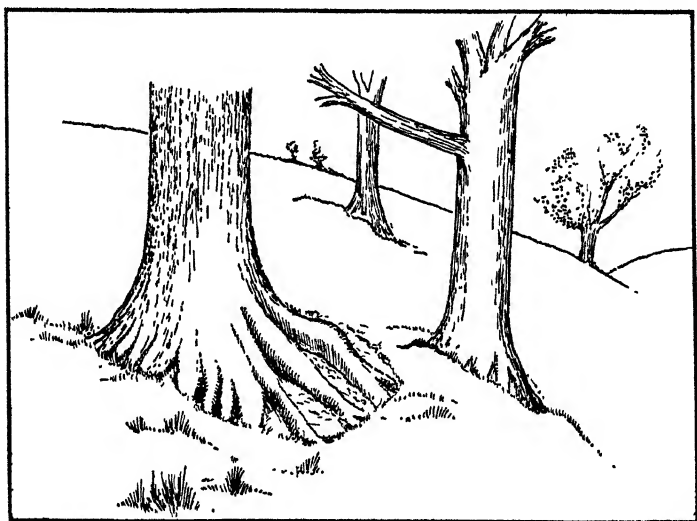
FIG. 18. TREES GROWING ON A SLOPE
The soil, creeping down the slope, has become banked up against the upper side of the trees.
On the lower side it has moved away and left the roots and subsoil bare.

the surface soil continues unbroken down the slope. Thus the tree,
standing midway in the flow, dams back the soil that is moving
towards it, while the soil below creeps slowly away. Similarly a
hedgerow running across the field acts like a dam on a larger scale
so that when you crawl through you may find quite a large drop in
level between the ground in front of and behind you.

In quarries and new road-cuttings other clues to this slow,
creeping movement of the soil may be seen. They are especially
clear when a distinctive layer of rock, such as a seam of coal or a
thin sandstone, occurs in the midst of clay (Fig. 19). This layer, as
it passes from the rock beneath into the cover of subsoil and soil,
is seen to bend and tail off downward in the direction of the slope.

Rain-wash and soil-creep have important consequences for mankind. Because of them soil is always being carried from the upper parts of the hillsides down to the lower and into the valleys. This explains why soil is often so thin on the hills and so deep and fertile on the valley-sides and floor (Fig. 20).

But not all soil that is loosened by the rain comes to rest in the valley. When the rain is heavy much of the water with its load

FIG. 19. A ROAD-CUTTING, TROWELL, NOTTINGHAMSHIRE

This shows a seam of coal, four feet thick, coming up from beneath the solid rock on the left and entering the subsoil and soil above on the right. The surface of the ground is sloping towards the right, and the soil has crept slowly down in that direction. The contribution made by the coal to the formation of the soil has crept along with it and has been drawn out into a thin layer which bends over and follows the direction of the slope.

By courtesy of W. Sutcliffe, Esq.

comes together in little runnels and forms streams which flow into the rivers. Thus much of the soil is carried far away from the area where it was first formed.

Normally this removal of soil by rain and running water is so slow that the loss is balanced by the formation of new soil from the rocks, for the part played by trees and hedgerows is repeated on a minute scale by every little plant, by every grass and flower. Taken all together, their leaves soften the blows of the raindrops on the soil, and their roots anchor it to the subsoil and the rocks beneath.

Pioneers opening out new lands have not always been aware of these facts or of their importance. They have cleared the forests from great areas, and stripped away the sheltering carpet of natural herbs and grasses from hundreds of square miles. It is true that they have covered these areas with their own crops, but only for part of the year. During the remainder of the time the ground has

FIG. 20. A VALLEY IN WALES

On the steep slope in the foreground the soil is stony because the more completely pulverized portion has been removed by rain, thus leaving the subsoil exposed. The soil washed away has begun to accumulate on the lower slopes, but even there it creeps slowly on until it reaches the valley floor, where it accumulates to its maximum thickness. The distribution of the cultivated ground roughly coincides with that of accumulating soil.

The valley is one that has been glaciated (p. 112). This is indicated by he U shape of its cross-section and by the steep, truncated tips of the adjoining spurs.

On the skyline the upland plateau exhibits the low relief and gentle slopes of an uplifted peneplain (p. 132).

By courtesy of J. E. Prentice, Esq.

been left bare. In dry weather the wind has blown the loose soil away. In wet weather the rain has washed it rapidly down the slopes to be carried thence by runnels and streams. The result has been that in the United States, in Africa (Fig. 21), and in India millions of square miles of fertile land have been changed to sterile desert.

Some of the rainwater, instead of running away over the soil, soaks down through it, dissolving its more soluble constituents, such as lime and gypsum. These are carried farther down into the

rock beneath.   Sooner or later the water escapes to the surface once more in the form of springs, and, with its load of soluble substances, flows into the streams and rivers.

Fig 21   KANAM, KENYA

In the foreground a fertile area has been changed to a desert by excessive soil erosion   Compare this with the background, which, as yet, has not been affected.

By courtesy of P F Kent, Esq.

Whether these processes be slow or speedy, all the soil formed by the destruction of the rocks in the end finds its way into the sea. What happens to it there is the next mystery we must try to solve.

ROLLING STONES

WHILE a river receives a burden of soil from runnels and tributary streams it collects up an extra burden of its own. If you have ever picnicked by a river or paddled in its waters you will be familiar with the fact that the bed of the river is covered with pebbles and boulders (Fig. 22; *Cf*. Fig. 107). Sometimes, as you looked down through the limpid water rippling over the gravelly bed, you have seen pebbles here and there slipping past their fellows on their

FIG 22   THE ARLANZON RIVER, SPAIN
The gravel and boulders which cover the bed lie exposed to view owing to the much-diminished flow of water during the summer drought (*cf*. Fig 106).
Photo H H Swinnerton

way downstream. When the river is swollen and is rushing along at a greater speed then all the pebbles will be on the move, hustling against one another as they roll along. Most of them started their journey far upstream among the hills. At first they were sharp-edged, angular stones that fell into the stream from the hillside or from collapsing banks. Driven along by the water, they knocked against one another and thus had their corners and edges worn   .
away. By the time they had travelled fifteen miles or so they had

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become those smooth, rounded pebbles we associate with running water. These are often described as ' water-worn pebbles,' but, of course, they were not worn by the water but by one another.

Sometimes in town you find a doorstep or path that has been worn hollow by the streams of people that for generations have passed that way. If you have seen that you will have no difficulty in believing that the continual procession of pebbles, rolling down-stream year after year, steadily hollows out the path along which it travels. That path is, of course, the bed of the stream. Sometimes,
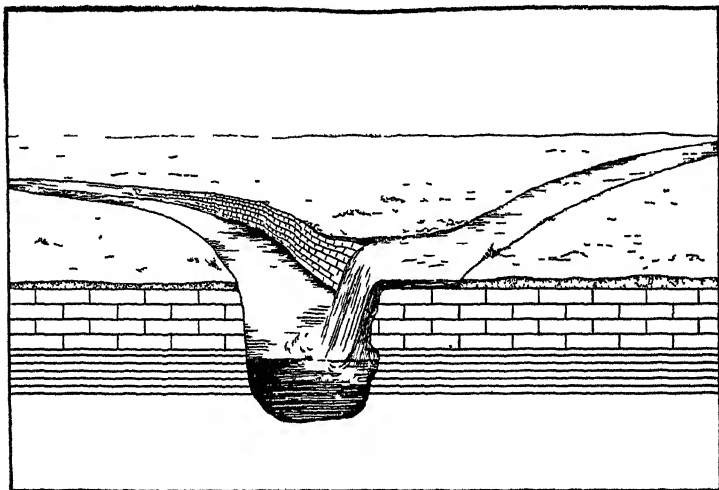
FIG 23   DIAGRAM OF A WATERFALL

The existence of the fall is due to the presence of a hard layer of rock underlain by some softer rock like clay or shale   The splash of the water, by wearing the soft clay away, undercuts the hard upper layer which, because it is no longer supported, collapses into the bed of the river   The waterfall, by moving upstream in this way, leaves a gorge behind along the lower part of its course.

where the bed is hard and rocky, a few pebbles get caught in a hollow. Here they stay but do not stand still, for the water as it swirls into, around, and out of, the hollow rolls the stones round and round, and grinds the hollow deeper and deeper until it becomes what is known as a ' pothole.' Where there are a number of such potholes side by side they gradually increase in size and eventually break into one another. Thus a new and deeper channel for the water is formed. If the river or stream can do this with its rolling stones where its bed is made of the hardest rock it is easy to realize that it will deepen its bed vertically, and more rapidly, when this is made of soft rocks such as clay and shale. This is particularly well shown

when a river flows across from hard to soft rocks, for then it cuts
the soft rock more rapidly than the hard, and a waterfall develops
at the junction of the two. At such a point the river attacks the
harder rock from below as well as from above, for the water splash-
ing up from the fall undermines the harder rock which, having lost
its support, cracks off and tumbles into the stream. Incidentally,
the waterfall itself travels a little farther upstream with every such
collapse (Fig. 23). As it does so it leaves behind it a much deepened
channel, or gorge.

FIG 24   CARDING MILL VALLEY, SHROPSHIRE
A typical V-shaped valley   Note the convex form of the sides and the way in which the spurs
from opposite sides interlock with one another
Photo H H Swinnerton

If the river worked alone it would, by the ceaseless wearing of
its bed, saw a deep, gorge-like channel across the landscape. But
it is not alone. The weather, using rain, frost, landslipping, and
soil-creep as its tools, attacks the sides of the channel and widens
it so that it becomes a valley. At first this is V-shaped (Fig. 24.
See Figs. 107 and 108), for in its upper reaches the river grinds at
its channel with maximum speed, thus, as it were, keeping pace
with the action of the weather. As it descends to lower levels it
grinds with decreasing vigour until eventually, in the lowlands, it
ceases altogether. Meanwhile the weathering processes continue

widening the valley (Fig. 25). The hills on either side gradually recede from the river, leaving in their trail the spacious, gently rising ground of the valley-floor clothed with deep, fertile soil formed from rain-wash and soil-creep.

At this stage in its journeyings the river, augmented by the
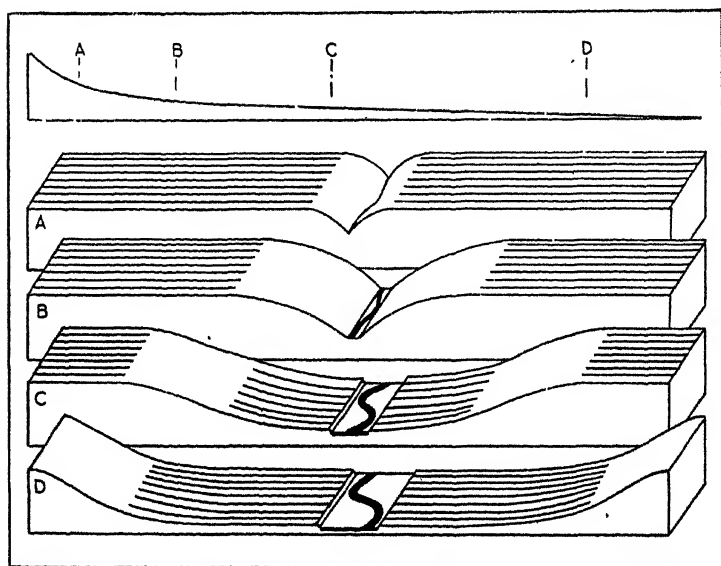
FIG. 25. DIAGRAM SHOWING THE CHANGES IN THE FORM OF A VALLEY

At the top is shown the normal profile along the valley path or the river-bed. This is called the curve of equilibrium.

(A) Section of a plateau traversed by a valley at point A in the curve of equilibrium. Note the broad stretch of soil covering the ancient uplands. (Cf. Figs. 105, 106, and 108.)

(B) With the increase in depth and breadth of the valley the area of the plateau is being reduced.

(C) As the river is now approaching sea-level it is flowing more slowly. It is no longer wearing its bed vertically, but is cutting its banks horizontally, thus forming a flat belt or flood-plain. Meanwhile weathering agencies continue to widen the valley and reduce the plateau still further. Soil-creep and rain-wash are covering the lower slopes of the valley sides with a blanket of soil.

(D) All traces of the plateau have disappeared and the valley is now very wide, with extensive areas of gently sloping ground covered with deep rich soil.

waters of many tributaries, no longer rushes tempestuously along (Fig. 26), but winds its way in leisurely fashion round meander after meander. Now and then in times of heavy rainfall (Fig. 27), or of rapidly melting snow, it swells into flood (Fig. 28), and with energy temporarily restored picks up a great load of gravel, sand, and mud. With these it bombards and wears away the outside banks of every curve (Fig. 29), and eats its way into the gently sloping ground on

either side, thus carving for itself a flat strip along the centre of the valley-floor. The limits of this strip are clearly defined by a steep, though quite often low, rise of ground called the ' river bluff.' Along this strip it lays down part of its load in the form of a thin veneer of alluvium. This is a deposit of gravel and sand more or less completely cloaked with mud, and laid down temporarily before
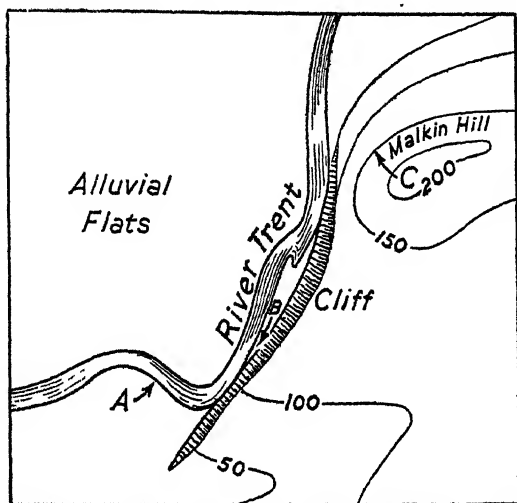
FIG. 26. A PLAN OF THE TRENT NEAR RADCLIFFE,
NOTTINGHAMSHIRE

The Trent here skirts the side of its vale. The lettered arrows A–C
indicate the view-points for Figs. 27–29.

being finally carried to the sea. The flat thus built up is called an **alluvial plain,** or ' flood-plain.' The process of building up goes on as long as the river, in times of flood (Fig. 30), spreads far and wide across the plain, and lays down upon it additional films of alluvial mud.

Eventually the river, with the remainder of its load of soil and rock-waste and its trail of pebbles, reaches a body of still water, a lake, or the sea. The river current continues out into the open water for some distance, but gradually it comes to a standstill. What happens to its load? The boulders, pebbles, and gravel stop rolling and gather together near the mouth of the river, but the soil is carried on. At this point a simple experiment will give us a clue to understanding exactly what happens to this soil. Get some soil from the garden and pour it into a tall bottle, or better still a

FIG 27   THE RIVER TRENT APPROACHING ONE SIDE OF ITS VALI

This view was taken from point *A* (Fig 26)   The river has caused the replacement of the sloping hillside by a steep cliff   To the left of the clump of trees on the skyline the profile of a portion of the slope which has not been removed can be seen

Photo H H Swinnerton

FIG 28   THE TRENT, RUNNING ALONG THE FOOT OF THE CLIFF

In times of flood the river covers the footpath and, by wearing away the soft marls on the left of the path, undercuts the cliff   From time to time the overhanging portions thus produced collapse for want of support   Thus the cliff is kept in being and the hillside is worn away

glass cylinder, until it is about two inches deep   Fill the vessel with
water and shake it vigorously until the soil is well scattered through-
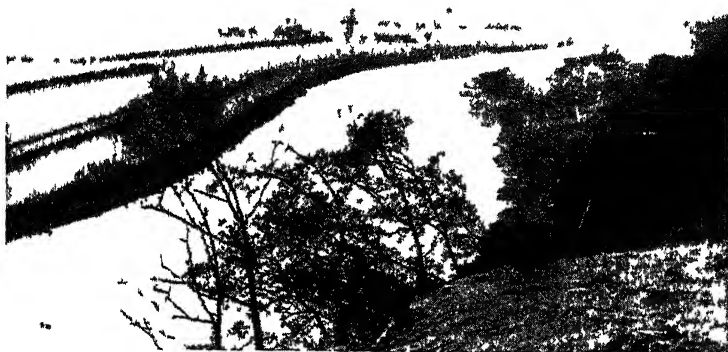
FIG 29   THE TRENT, SEEN FROM MALKIN HILL

The river is here seen passing away from the side of the vale and meandering across the flood plain
In the foreground the straight ridge running along the field on the left of the river is an artificial
embankment erected to keep the water off the fields during ordinary floods   On the right side
recently formed alluvium is seen

Photo H H Swinnerton

FIG 30   THE VALE OF THE TRENT AT A TIME OF ABNORMALLY HIGH FLOOD
The river itself is in the background more than a mile away and is usually invisible from the
viewpoint of this picture
By courtesy of W Sutchffe, Esq

out the water   Now stand it upon a table and watch.   In a minute
or two the coarser or sandy part of the soil will settle and form a

sediment at the bottom, but the fine dusty or muddy part will remain suspended in the water much longer. After an hour or so a layer of mud will have settled above the sandy layer. Even after some hours much of the finest mud will still remain in suspension.

Picture all this taking place in the river water as it flows out into the lake or the sea. The sand will settle more quickly, and so form a sediment on the floor of the water close to the shore. The mud, because it settles more slowly, will be carried farther. In time it too will settle to the bottom and form a layer of mud on the floor, but at a greater distance from the shore. Thus it comes about that though the boulders, gravel, sand, and mud all travel together in the river, when they reach the lake or sea they are separated from one another and are spread out on the floor—first the gravel, then the sand, and lastly the mud. Thus during a short period of time a layer of sediment, a **deposit**, is laid down, consisting in its different parts of gravel, sand, and mud. This process is being perpetually repeated, and thus layer after layer is laid down, one on top of the other.

Near the mouth of the river, where the coarser sediments fall, the layers are thicker, and rapidly pile up until they reach the surface of the water. Thus this part of the lake or sea becomes filled up and forms a flat area of low-lying ground called a **delta.**

TRAVELLING BEACHES

NEARLY every one enjoys a holiday at the seaside. Some prefer to go where there are rocky cliffs, others where the cliffs are low or absent altogether and the beach is covered with great stretches of sand. At both places may be found many clues that will help in unravelling the mystery of the earth's story, for much of that story is closely linked up with the sea.

A walk along the beach soon shows that it is not all sand. Indeed, the upper part of the beach may be covered with shingle and large pebbles, or it may be sandy on the whole with here and there patches of gravel. These are quite often arranged at regular intervals in the form of festoons, or **beach cusps** (Fig. 32). Sometimes they consist of shells instead of pebbles. The lower stretches of the beach usually consist almost entirely of sand with an occasional pebble or shell here and there. Evidently there has been something at work sorting out the pebbles and shingle from the sand. What is it?

If we recall what we have seen when bathing or paddling we shall find an answer to that question. First we recall the restlessness of the sea, with its surface for ever rocking up and down as an endless succession of waves races towards the beach. Out in the open the waves are like long, low swellings on the surface of the water. As they come on each swelling rises into a sharp crest which curls over forward and, at last, tumbles on to the front of the wave with a great splash and noise. When this happens the wave is said to break, and is then called a **breaker** (Fig. 33). But the water of the wave does not stop there; it swills up the beach for many yards as a sheet covered with bubbles and flecks of foam. As it does so it rolls any pebbles or shells it encounters up the beach. The sheet then flows back, leaving these behind but taking some of the sand with it as it runs to meet the next oncoming wave.

Each day, as the high tide comes farther up the beach, this process is repeated, so that at last, with the highest spring tides, the gravel and shingle arrive at the top of the beach. When a strong breeze is blowing off the sea the waves are much larger and the work of sorting goes on more vigorously.

Now, if we watch the waves more closely we shall see that a long wave does not strike the shore along the whole of its length at exactly the same time, for its length makes an angle with the shore-line. The result is that when it breaks its water swills obliquely up across the beach. Any pebble it strikes is therefore driven along the beach as well as up it. Since this happens to all the pebbles and the sand, the whole of the beach, like the soil on a hill slope, is on the move. Like that, it is travelling, but much more
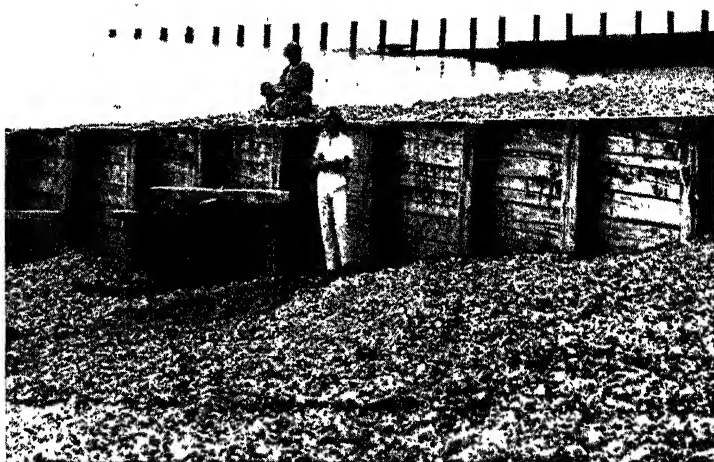
FIG. 31. GROYNES ON THE SUSSEX COAST

The way in which the gravel is piled up against one side of the groyne and washed away from the other shows how effectively the breaking waves shift the beach along.

Photo H. H. Swinnerton

rapidly. We usually take our holidays in the summer-time, when the sea is in a gentle mood, but in winter months, when great storms break, huge quantities of gravel and sand may be shifted along the coast in a few hours. The authorities at the seaside naturally do not want their beach to go travelling elsewhere, and therefore they erect wooden walls, or groynes (Fig. 31), across the beach. The difference in the level of the beach on the two sides of the groyne bears witness to the wisdom of the authorities.

Sometimes the beach, as it travels, comes to a point on the coast where a river flows into the sea, but that does not stop its journey. On the other hand, the river is not stopped by the beach, for the

FIG. 32. THE LINCOLNSHIRE COAST CHAPEL ST LEONARDS

The beach consists mainly of sand with scattered pebbles. Along the line reached by the last high tide, pebbles are congregated close together in festoon-like heaps, or beach cusps. In the background is a series of sandhills, built up of sand blown from off the beach and held in position by a coarse type of grass which flourishes in such situations. In the middle distance a wooden groyne crosses the beach.

Photo H. H. Swinnerton

FIG. 33. THE INCOMING TIDE

The foam-covered water a little distance from the beach is the breaker line. The water from each wave as it breaks swills up the beach in a way which explains the formation of beach cusps.

Photo H. H. Swinnerton

D

two compromise with each other. The river turns aside, and, flowing parallel with the beach, prevents this from joining the coast on the other bank. Thus the beach, continuing its journey, lengthens out into a spit along the seaward side of the river (Fig. 34).

At other times the beach comes to a point where the coastline
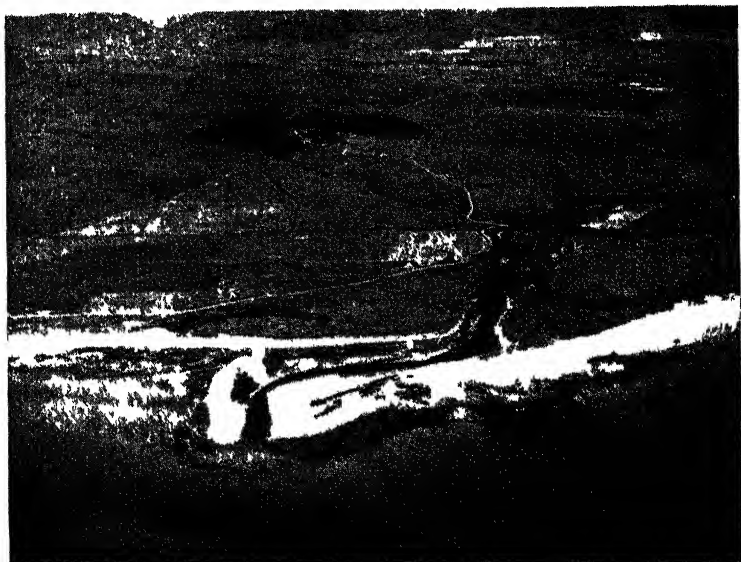
FIG 34   AN AERIAL VIEW OF THE WEST COAST OF THE ISLE OF ARRAN

The narrow coastal plain is drained by a small, meandering stream which, after receiving a tributary on its right bank, flows into the sea   The beach travelling from right has shifted the mouth of the river towards the left by forming a spit.

By courtesy of D. J Tugby, Esq

bends sharply backward into a bay. Instead of going round the bend, it carries on in the same direction as before and builds up a spit across the bay. As it does so it may encounter an island which thus becomes linked on to the mainland by an isthmus of shingle or sand. One famous example of this is Chesil Beach, which stretches out towards, and is joined on to, the Isle of Portland.

ROCKY SHORES

A ROCKY shore presents a striking contrast to the one studied in the last chapter, and offers delights that are peculiarly its own. Its beach is usually much smaller and steeper. A strip of sand may be exposed at low tide; elsewhere it is cumbered with shingle, boulders, or even great blocks of stone lying on a rocky floor. Scrambling, rather than walking, is the order of the day. On a shifting, sandy beach there is no foothold for seaweeds and sea-snails, but here in the rock-pools and in the gullies, where the water rises and falls with every wave, forests of seaweeds sway to and fro. Little fishes, shrimps, and other creatures flash about, and, as we watch, time flashes too. Shellfish abound; limpets, mussels, dog-whelks, in hundreds and thousands; sea anemones, brittle stars, crabs, are there, and each makes its contribution to our pleasure and delight. Overlooking all this are cliffs towering to dizzy heights above us. Could anything appear more steadfast and abiding? Nevertheless, the fact that those stones and boulders which are strewn about are of the same kind of rock as the cliffs arouses our suspicions.

Sometimes, when the winds are strong and the tide is high, scrambling along the beach is out of the question. Then we must be content to look on from some vantage-point on the cliff while great waves come pounding among the boulders, splashing the water high in the air and broadcasting spray, beautified now and then by rainbow bands of colour. In winter, when the storms break in fury along the coast, mighty breakers roll the boulders about like pebbles, or fling themselves like giant battering-rams against the cliffs with a force of as much as two, three, or more tons to every square foot. As they break they pick up the gravel or small boulders as though they were sand, and with these they deliver every minute multitudes of blows before which even the hardest rock on earth must yield (Fig. 36). Storm succeeds storm, winter follows winter, and gradually the cliff is undermined at its base and is left overhanging. Sooner or later the face of the cliff left thus unsupported collapses on to the beach, and so provides

the waves with more munitions for their destructive work. This
undermining and collapsing is repeated unceasingly, and gradually
the land, whether high or low, is sliced away.

The cliff face is, of course, not of uniform strength all along the
line. Here and there, where weak places occur, undermining
progresses more rapidly into the face of the cliff, and excavates
caves (Fig. 35). Sometimes a buttress of rock sticks out beyond
the line of the cliffs. The waves then attack this on either side and
grind a tunnel-like cave right through. The buttress then looks
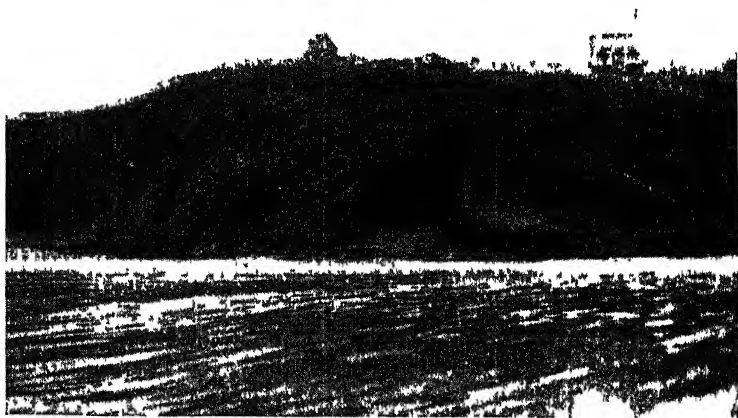
FIG 35   THE PEMBROKESHIRE COAST AT LITTLE HAVEN
A cave has been excavated by the waves along the centre of an upfold of rocks (p. 66).
Photo H H Swinnerton

like a bridge, and is called a ' natural arch ' (Fig. 37). In due time
the arch also collapses, leaving the outside supporting pier standing
alone, a solitary pinnacle of stone in the midst of the restless waters.
Such pinnacles, or **sea-stacks** (Fig. 38), may often be seen along
rocky coasts.

It is difficult to believe that all this turmoil is confined to the
surface of the sea. Nevertheless, waves fifty feet long from crest
to crest hardly disturb the water fifty feet below. Down there all
is as calm and placid as a lake, and thus direct destructive action of
the waves is limited to a shallow zone. Above this the cliffs
recede and with them the margin of the land. Below it only the
foundations of the land remain worn down now to an almost level

FIG. 36. THE GLAMORGAN COAST

Limestone cliffs are here seen undercut by the action of the waves. Sooner or later the over-
hanging portion will collapse, and so the cliff will recede   The curious shapes seen on the surface
of the rocks below show that the waves act partly by dissolving the limestone.

By courtesy of J. H. Wilde, Esq.

surface known as the 'wave-cut platform' (Fig. 39). Part of this may be seen exposed to view as a rocky beach when the tide is low.

When a wave containing thousands of tons of water has delivered its blow against the cliff the water cannot go back the way it came along the surface, for that is barred by the never-ending procession of oncoming waves. Its only path back is underneath that procession. This backflow is called the 'undertow.' So, then, the

FIG. 37. DURDLE DOOR, DORSET
A natural arch in Portland Limestone.
By courtesy of P. E. Kent, Esq.

calmness of the deeper water is not one of stagnation. It is the calmness of the still waters of a river that runs deep.

When there is calm on the surface of the sea the undertow almost ceases to flow. With every increase in roughness on the surface the flow strengthens. During a storm it flows like a great river in flood, rolling small boulders and pebbly gravel out across the wave-cut platform. Just as the constant traffic of stones wears away a river-bed, so this broad sheet of shingle and gravel wears down the whole surface of the landward margin of the platform and gives to it a concave slope (Fig. 40).

As the undertow passes into deeper water it spreads out its load of waste, formed by the destruction of the land, upon the sea-floor after the same manner as the river—first the gravel, beyond that the sand, and yet farther out the mud. It does this, however, on a
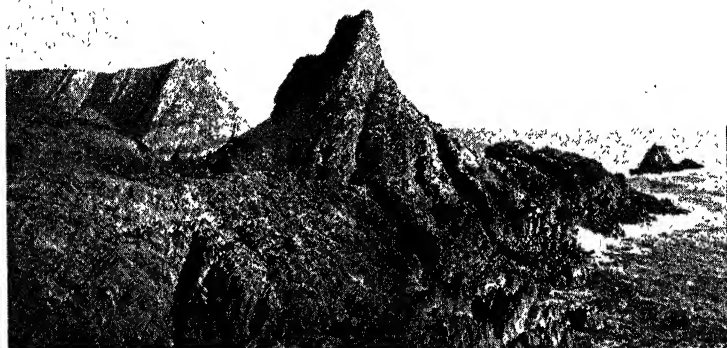
FIG. 38. THE GOWER COAST

On the right is a modern sea-stack. In the middle an ancient sea-stack stands up from the surface of a raised beach (p. 59). In the background a small cave has developed along a bedding-plane.

By courtesy of T. W. Taylor, Esq.
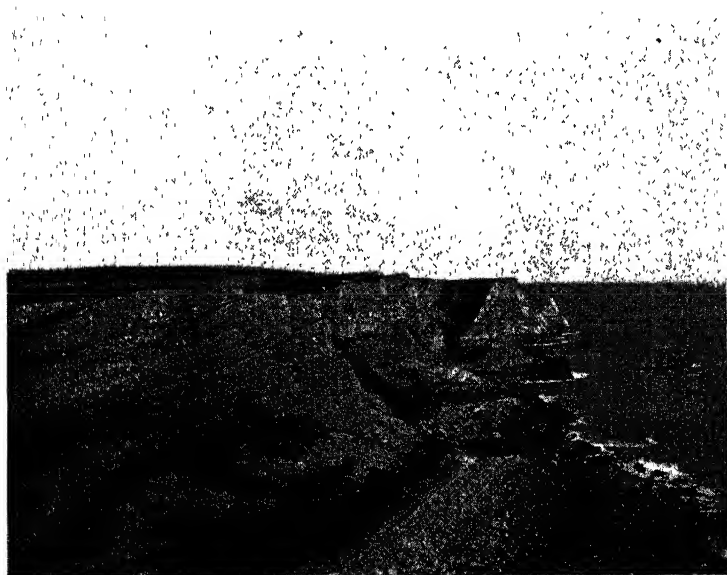
FIG. 39. THE GOWER COAST

In the foreground is a rocky, wave-cut platform. On the right the beds of rock have a steep dip (*cf.* Fig. 49) which diminishes towards the left until it has become quite gentle. The land surface shows the mild relief of a peneplain (p. 132). The way in which this passes across the upturned edges of the rocky layers is testimony to the vast amount of denudation which has taken place.

By courtesy of T. W. Taylor, Esq.

much vaster scale, for the undertow is like a river that is as broad
as the coastline is long.   In the deposits thus formed are buried the
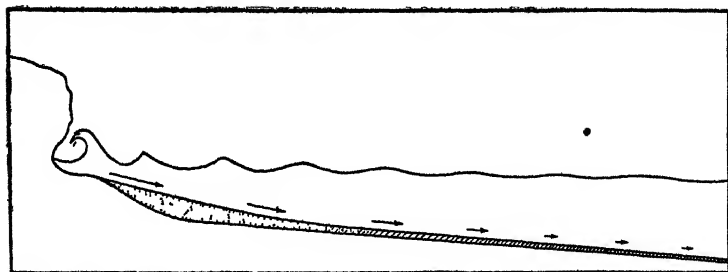
FIG 40   DIAGRAM ILLUSTRATING THE FORM OF THE WAVE-CUT PLATFORM

The course of the undertow is shown by the arrows, the progressive shortening of which indicates
the declining strength of the current.   The shaded area represents the way the deposits are spread
out on the sea-floor with the coarse gravel and sand near the shore and the fine mud farther afield

shells of innumerable animals that lived on the floor of the sea and
in the water above.

CHAPTER IX

TERRA FIRMA?

TERRA FIRMA—what could be more stable and enduring than the land? Why, then, is there a question-mark in this chapter-heading? Let us see.

People who keep their eyes open when on holiday at the seaside often come upon things that are mystifying. Among these is something they find here and there on sandy beaches when the tide is

FIG 41   A SUBMERGED FOREST, CHAPEL ST LEONARDS, LINCOLNSHIRE
The tree-stump in the foreground has a diameter of five feet   The flat-topped hummocks are capped with peat, which, in some places, is as much as three feet thick   Note the other tree-stumps which stick up here and there above the peat.
Photo H H Swinnerton

very low, such as the stumps of trees sticking up out of the beach and often surrounded by great patches of peat. Buried in this peat they find branches and even trunks of forest trees. At first they are inclined to think that these are trees that have been carried to the spot by the sea, but when they find the roots of the trees going deep down into the ground below the peat and the beach they become convinced that the stumps stand just where the trees grew. Now, at high tide the peat and stumps may be submerged under ten or even twenty feet of salt water. Evidently, then, at the time

when these trees were alive, the ground must have been above the level of the highest tides—that is to say at least twenty or thirty feet above its present position. The ground must therefore have sunk at least that amount since the trees were alive (Fig. 41). These **submerged forests,** as they are called, may be seen at many places along our own and other coastlines (Fig. 42).

At Ingoldmells Point, on the Lincolnshire coast, there are the remains of ancient British salt-works, and of a Roman station, on the beach (Fig. 43). These are covered by the high tide every day.
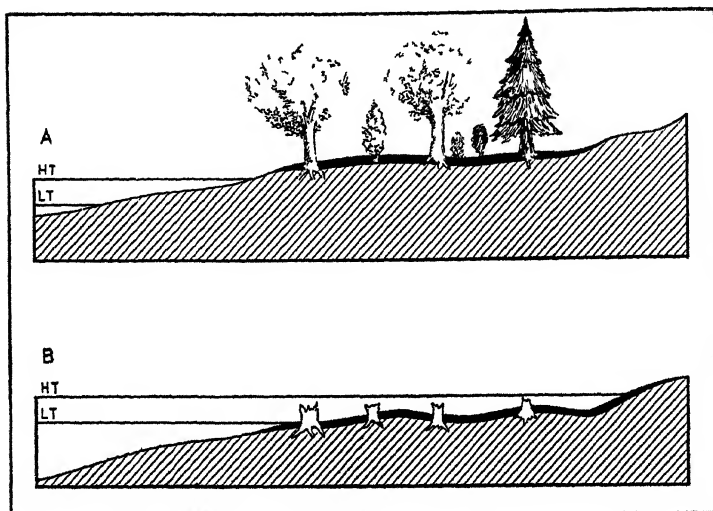
FIG. 42.   DIAGRAM TO ILLUSTRATE THE HISTORY OF A SUBMERGED FOREST
A the forest as it was about 2000 B c , with peat forming on the ground , *B*, the forest to-day ,
H T , high-tide level , *L.T* , low-tide level

But the ancient Britons and Romans were far too sensible to live and work in places that were flooded by the sea every day. We may conclude, therefore, that in their time the ground, which now forms the foundation of the beach, must have been at least ten feet higher than it is to-day, and that in succeeding centuries it has sunk gradually down to its present level. On other coastlines such downward movements have resulted in the drowning of the valleys and the consequent formation of long inlets, shut in by promontories formed from the hills which once separated the valleys (Fig. 44).

In contrast to this, at other places there may be seen behind the present beach a nearly flat shelf of ground overgrown by grass and backed by steep slopes leading to the upland beyond. The waves

running across the present beach have cut a line of tiny cliffs only eight or ten feet high along the margin of the shelf (Fig. 45). In these can be seen gravel and sand resting upon a flat platform of rock, which looks strikingly like a wave-cut platform. The idea that it is such a platform is confirmed by the discovery that the sand and gravel which rests upon it, like the sand and gravel of the beach itself, contain sea-shells. Beginning to realize that this is an ancient beach, we naturally look for the sea-cliffs, and find only a
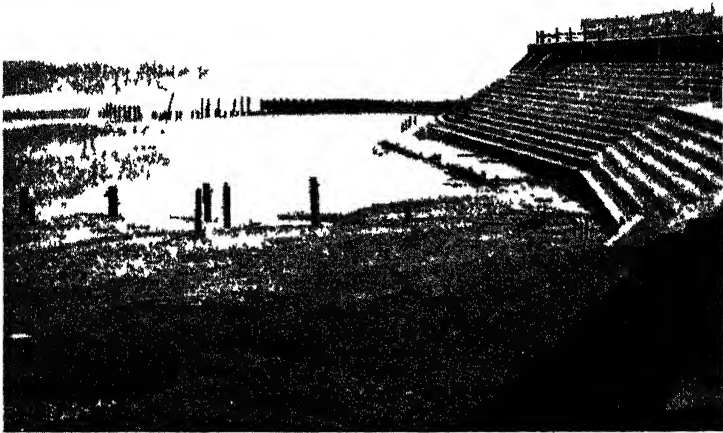
FIG 43 INGOLDMELLS POINT, LINCOLNSHIRE

At high tide the water rises more than half-way up the concrete steps. The foreground, from which the sand has been washed away by the sea, is made up of the occupation earth of a Roman station, and has yielded numerous fragments of third-century pottery

Photo H H Swinnerton

steep slope. That is a disappointment until we recollect that if the sea has not been at this level for a long time then there has been nothing to undermine the cliff and so keep it in being. Meanwhile frost has chipped away the top edge of the cliff and piled up the debris at the foot. This process has been followed by rain-wash and soil-creep, and thus the cliff has been changed to a steep slope. Having overcome that difficulty, we feel at liberty to conclude that at this place the ground has risen to a higher level, and lifted what was once an ordinary beach above the reach of high tide, to become what is called a ' raised beach ' (see Fig. 38).

In Scotland there is a series of such beaches at levels of about
25 feet, 50 feet, and 100 feet respectively. In many other parts of
the world also similar series of marine terraces gird the coastlines
(Fig. 46).

The same movements that have lifted these beaches have also
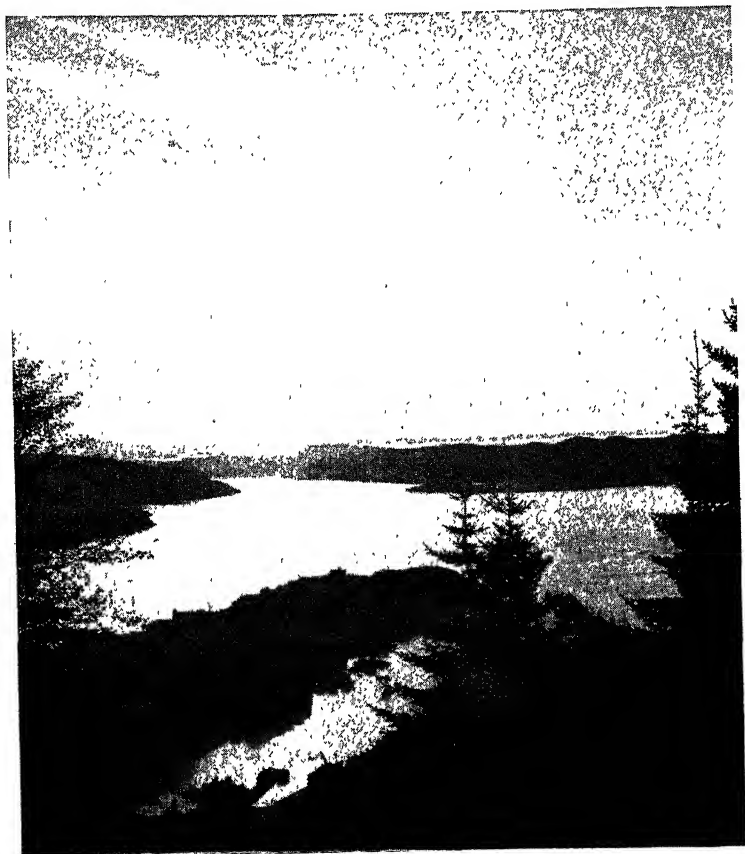
FIG. 44. A SUBMERGED COASTAL PLATFORM, BERGEN, NORWAY
By courtesy of T. W. Taylor, Esq.

raised the adjoining sea-floor so that parts of it have become dry
land. At the same time the successive carpets of gravel, sand, and
mud laid down by the undertow become the rocks which form the
foundations of this new-born land, and the shells they enclose
become the fossils about which there is so much to be said in later
chapters.
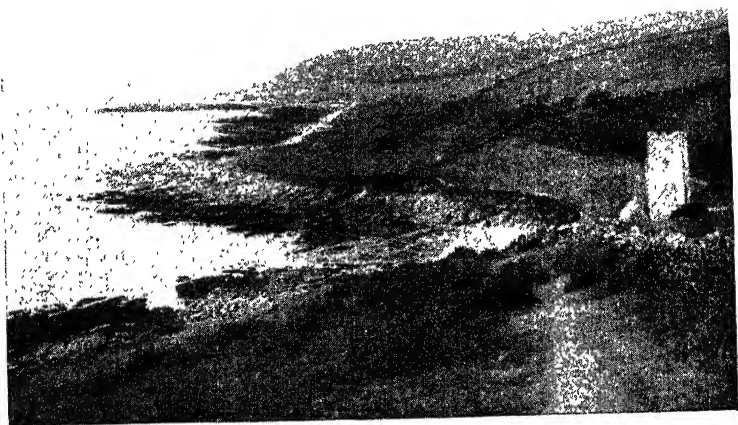
FIG. 45. A RAISED BEACH, WEMBURY, DEVONSHIRE
Photo H. H. Swinnerton

FIG. 46. A RAISED CORAL REEF, MOMBASA
The flat ground adjoining the sea is a wave-cut platform now standing about thirty feet above
sea-level. An earlier and higher platform with a bungalow upon it is seen in the distance.
By courtesy of P. E. Kent, Esq.

All these facts give us the clue to the understanding of another mystery. Right in the heart of England, in the Derbyshire hills, thick masses of limestone are found, consisting largely of corals and of the shells of many kinds of sea animals (*cf.* Fig. 6). People are frequently surprised when they first see these and exclaim, " How did these shells and corals get here ? Surely the sea never covered these hills ? " Our study of submerged forests and raised beaches gives us the beginnings of an answer to those questions. They have taught us that land may sink and the sea-floor rise, that indeed sea and land may change places. True, these hills are more

FIG 47   RIVER TERRACES, WHEELDALE BECK, YORKSHIRE
The flat tops of the terraces are relics of the earlier flood-plains formed by the beck
Photo H H Swinnerton

than a thousand feet high, but it is natural to say, " If beaches and sea-floor can rise twenty-five or a hundred feet why not a thousand feet ? " Here, then, in this limestone is a rock formed out of the mud and the shelly remains of sea animals which were deposited on the floor of some ancient sea. These deposits, now converted into rock, have been slowly lifted up a thousand feet or more.

What a picture that rock, with its fossils, gives us of an ancient sea situated where England now stands. A sea dotted with coral reefs, swarming with shell-fish and miniature forests of stone lilies, and many other creatures that flourish only in the clean, sunlit waters of warm, tropical seas. Storms beat upon the reefs, as they still do against our present rock-bound shores, smashing up the corals and grinding parts of them and the shells of other creatures

FIG. 48. A PANORAMIC SKETCH OF THE SEVERN VALLEY, BRIDGNORTH, SHROPSHIRE

In the middle foreground is the present flood plain of the river   Right of this the ground rises by two prominent steps, or river terraces   Similar terraces can be seen in the distance on the left   The upper town is situated on one of these

to shelly sand or limy mud. The undertow then swept these out into the depths and spread them upon the sea-floor. In due time they hardened into limestone, and were raised up to become the hills of Derbyshire.

Snowdon is nearly 4000 feet high, and yet at its topmost point is a layer of rock crowded with fossil sea-shells. If you ever find them you will now no longer be mystified. Nor will you be mystified if during a holiday in the Alps, or some other great mountain area, you find, as others have found, fossils in mountain peaks that stand thousands of feet above sea-level. The mystery solved fills us with wonder and awe !

The same movements which lift the sea-floor until it becomes land also lift the valleys with their rivers and alluvial plains. Before uplift each of these rivers had almost completed its work. It had ceased to cut its bed, because it had excavated this almost to sea-level. But when it was lifted, it may be, only twenty or forty feet, it set to work again grinding at its bed. Such a river is said to have been 'rejuvenated.' Quite soon a narrow, steep-sided valley develops within the alluvial plain, and in due time this is widened into a new alluvial plain at a lower level. This new plain, as it widens, encroaches on the old one until only narrow strips and fragments of this remain on either side. Such remnants of an old alluvial plain left as fringes alongside a new one are called 'river terraces ' (Fig. 47). When upward movements of the land are repeated a series of terraces at successive heights may be formed (Fig. 48). As these approach the coast they merge into the corresponding marine terraces already described.

CHAPTER X

ROCKS BENT AND BROKEN

THAT rocks can be broken is a familiar fact, for most of us at one time or another have smashed stones with a hammer. But it is difficult to imagine that such brittle stuff can bend. A simple experiment will, perhaps, help us to see that this is quite possible. You know from previous experience that sealing-wax is very brittle and breaks easily, even when it is tapped only gently with a hammer. By means of some device fix a stick of the wax in a horizontal position, with one end firmly held and the other free. Heat a pin and push it, while still hot, into the top side of the free end. When
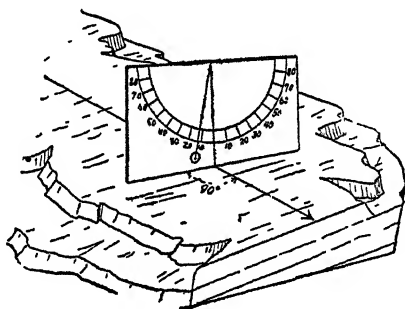
FIG. 49. DIAGRAM ILLUSTRATING TILTED ROCKS

Such rocks are said to be dipping. The direction of maximum tilt is the direction of full or true dip. The amount or angle of dip is measured by means of a clinometer. The line at right angles to this direction is level and is called the line of strike.

From Grabau's " A Text-book of Geology," Part I

(Drawn by Mary Welleck)

this is quite cold and firm tie a piece of string round this end and around the pin. Now fasten a weight, two ounces or more, to the free end of the string and leave it to hang there for several days. It will then be found that, in response to this gentle pressure applied for that long time, the very brittle stick of wax has bent considerably.

·Rocks do not, of course, occur as projecting rods, but as layers lying one above another. They are therefore amply supported from beneath like piled-up sheets of paper or pieces of cloth resting upon

E

a table. If you press your hands against the edges of such a pile the sheets will be seen to bend into folds. The pressure applied to the sealing-wax was vertical, that applied to the sheets is described as lateral. It is by such pressure that rocks are tilted and folded (Fig. 49).

Quite often in quarries and sea-cliffs the layers of rock are seen to have been folded (Fig. 50. *Cf.* Figs. 35 and 39). An upfold is called an **anticline** ; a downfold, a **syncline.** The top of the former is its ' crest ' : the bottom of the latter is its ' trough.' The sloping beds on either side are its ' limbs.' The geometrical plane which
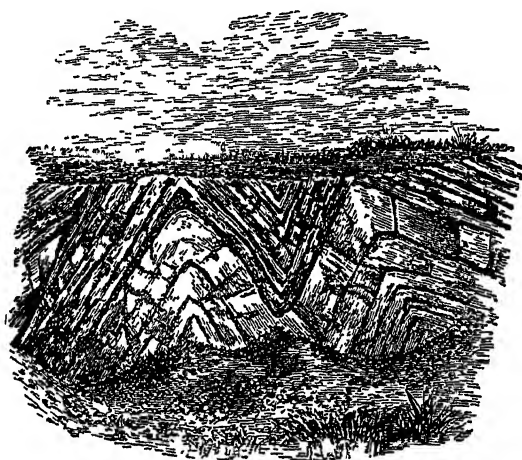
FIG. 50.   A NATURAL EXPOSURE OF FOLDED ROCKS
The rocks are bent into upfolds, or anticlines, and downfolds, or synclines
From Grabau's " A Text-book of Geology," Part I
(After Geikie)

divides the fold equally is the **axial plane,** and any line in this which is parallel to the crest or trough is the axis of the fold. If the axis be tilted the fold is said to be pitching (Fig. 51). When the axial plane is vertical the fold is symmetrical, but if it be inclined the fold is asymmetrical. Sometimes the crest of a fold falls over like a breaking wave and thus becomes an **overfold.** A very tall fold that is lying on one side is a **recumbent fold** (Fig. 52).

All such folding, occurring as it does in such varying degrees of intensity, is generally assumed to have been due to lateral pressure. What precisely caused the pressure is still an unsolved problem, for which a number of solutions have been suggested. An early suggestion was that as the earth cooled it shrunk, and the crust,

adjusting itself to the smaller figure, became wrinkled like the skin of a wizened apple. A later suggestion, now much in favour, is that large slabs of the earth's crust move sideways over its surface and squeeze the strips that lie between.

Rocks do not, however, always fold when subjected to lateral
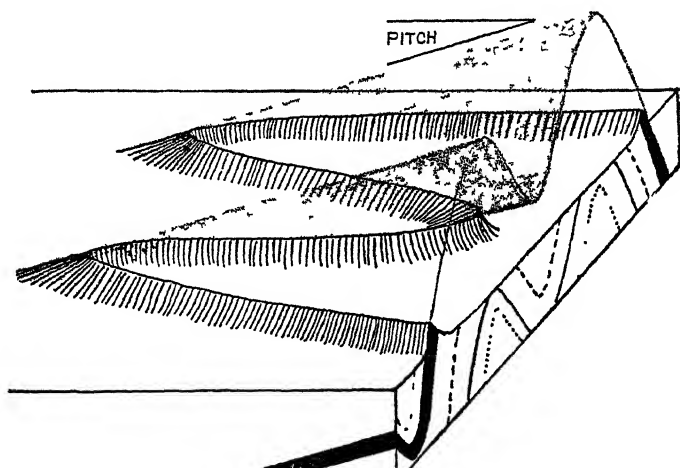
PITCH

FIG 51   DIAGRAM SHOWING PITCHING FOLDS
Observe the form of the surface features resulting from the wearing away of the folds.
From Grabau's " A Text-book of Geology," Part I
(After F K. Morris, "Military Geology"

pressure ; they often crack and break (Fig. 54). Such fractures are called **faults**. The rocks on one side of the plane of faulting may be pushed over those of the other side. Such a structure is spoken of as a **reversed fault**. In some cases the slope of the plane

2   3   4
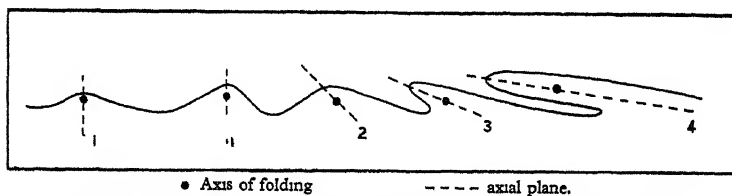
● Axis of folding   – – – – axial plane.
FIG. 52. DIAGRAM SHOWING DEGREES AND TYPES OF FOLDING
1, Symmetrical fold , 2-4, asymmetrical folds ; 3, overfold ; 4, recumbent fold.

may be steep, and the amount of sideway movement quite small. In other cases the slope is gentle, and a mighty mass of rock may have slid ten or more miles across the rocks beneath. This structure is called a **thrust** and the plane of sliding a **thrust plane**. This

sheet-like mass that has been carried forward out of its normal
position on to an adjoining area, either by thrusting or by recumbent
folding, is called a **nappe**, and is a common feature in great
mountain ranges.

In regions of folding, reversed faulting, and thrusting the total
result is a reduction of the area occupied by the rocks that are
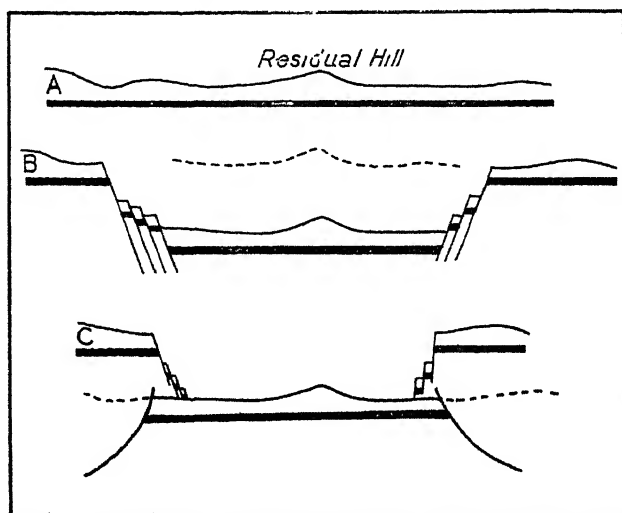
Fig 53 DIAGRAM ILLUSTRATING TWO POSSIBLE MODES OF
ORIGIN OF A RIFT VALLEY

A. The original unbroken peneplained surface. *B.* Owing to the stretching of the
region normal faulting has taken place, the centre of the peneplain has dropped
down between the uplifted sides. *C.* Owing to the compression of the region
thrust-faulting has taken place, the sides of the peneplain have been pushed towards
one another over the margins of the central portion which has gone down. The
overlapping portions of the sides have landslipped down on to the valley floor.

affected. They may therefore be described as **regions of pressure.**
More will be said about them in a later chapter.

In other regions faulting of a different kind occurs. The rocks
on one side, instead of being pushed over those of the other, have,
so to speak, been pulled apart, and have collapsed against one
another at a lower level. In this case the rocks on the upthrow side
of the fault plane lie at a higher level than those of the downthrow.
This type of fault, known as a ' normal fault,' occurs most frequently
in regions that have been stretched, or **regions of tension.**

The great rift valleys of Africa are long strips of country that
have gone down between two lines of faulting (Fig. 53). Opinions
differ, however, on the question whether the faults are normal or
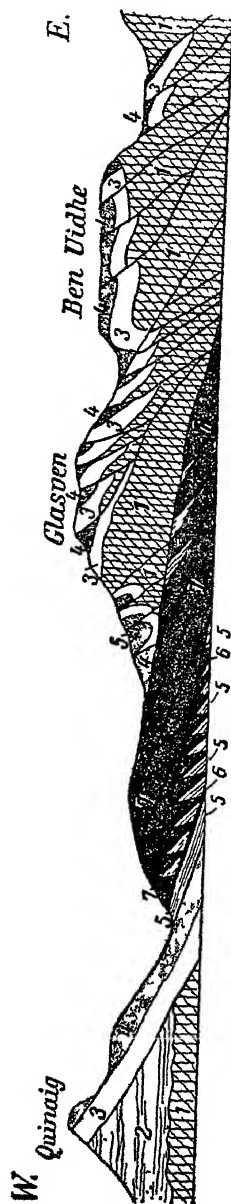
FIG. 54. A SECTION OF THE NORTH-WEST HIGHLANDS OF SCOTLAND

The rocks are much broken by reverse faulting and thrusting. The very ancient rocks (1) shown in their natural position on the left, are seen on the right pushed far out of place, so much so that they sometimes lie on the top of much younger rocks (7). The length of the section is about seven miles.

From Grabau's "A Text-book of Geology," Part I

(After Scottish Geological Survey)

reversed   The Rhine Valley and the Midland Valley of Scotland seem to be the outcome of normal faulting, but are of more ancient date (Fig 55)

In some cases normal faulting results from differences in vertical pressure   Thus, for example, it has already been seen that rock waste is carried away from the land and deposited on the sea-floor. This process may continue for a long time   Under the new load thus laid upon it the sea-floor sinks, while the land, relieved of load, rises (Fig. 56)   The rocks between may be strong enough to resist
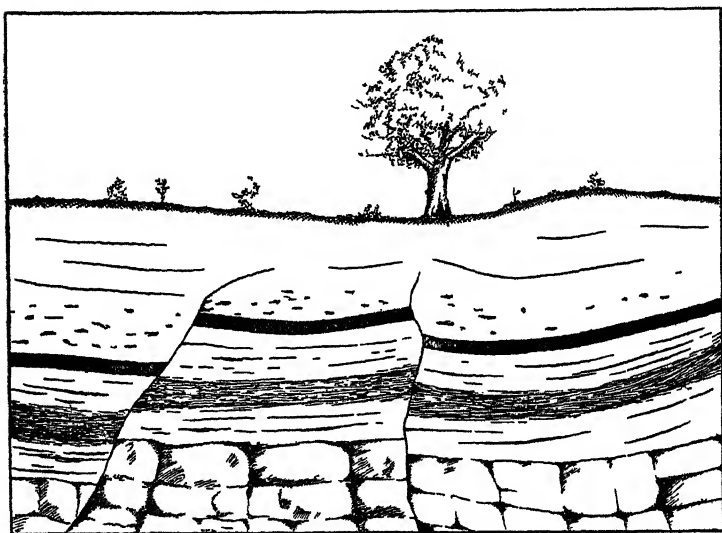
FIG 55   A QUARRY FACE—KIMBERLEY, NOTTINGHAMSHIRE
The rocks, including a thin coal seam, have been broken by two faults

the strain which these differences of pressure put upon them for an indefinite period (Fig. 57), but sooner or later they yield by snapping along one or several planes, those on one side moving up, those on the other down (Fig. 58).

If the snapping and movement of the rocks takes place suddenly the whole region receives one of those great jolts that are called **earthquakes.** The vibration that is set up travels in waves around the surface of the earth and through its deeply seated portions. In the area above and around the centre of commotion many striking phenomena are manifested. The ground shakes, loose soil and stones are thrown into the air ; the sea is thrown away from the shore only to return as a great devastating wave upon the land,

FIG 56   GREAT RIFT VALLEY, KENYA

Just beyond the wall the face of the fault scarp drops steeply for 1500 feet   In the middle distance minor fault scarps run parallel to the main scarp   In the background a volcano rises from the floor of the valley

By courtesy of P E Kent, Esq

FIG 57   THE FLOOR OF THE GREAT RIFT VALLEY, KENYA

The scarp which bounds the valley on the north is seen in the background   On the right, in the middle distance is a residual hill which formed a feature on the peneplain before this was broken by faulting

By courtesy of P E Kent, Esq.

carrying shipping inland, destroying towns, and drowning thousands of people ; fissures a foot or more wide and sometimes hundreds of miles long open and close again.   " What ailed thee, O thou sea, that thou fleddest ? thou Jordan, that thou wast driven back ?   Ye mountains, that ye skipped like rams ; and ye little hills, like lambs ?
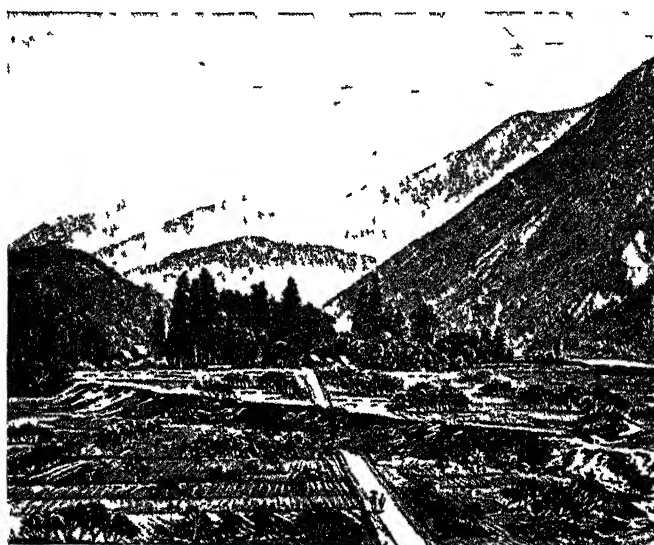
FIG 58   NEO VALLEY, MIDORI, JAPAN
View of the great fault produced during the earthquake of 1891.
From Grabau's " A Text-book of Geology," Part I
(After B Koto)

Tremble, thou earth, at the presence of the Lord." (Psalm cxiv, verses 5–7.)   " And the earth opened her mouth, and swallowed them up. . . . The earth closed upon them : and they perished." (Numbers xvi, verses 32, 33.)

PART II

THE SEARCH CONTINUED

CHAPTER XI

THE XYZ OF ROCKS

IF you were asked to name some rocks you know which have not been mentioned so far, one of the first to be named by you would be **granite**—a rock that is often used for buildings and monuments where strength and durability are essential. Let us now examine this rock carefully.

First look at a moderately large piece of granite closely, using a magnifying glass if necessary. It will be seen that the rock is made up of three different substances (Fig. 60). The commonest of these is white or pink in colour and may be present in quite large pieces that have regular shapes with some straight sides and flat, shiny, broken surfaces. The spaces between are partly filled with smaller pieces of the same material. This substance is **felspar**.

The small irregular spaces between the felspars are filled with a colourless, glassy-looking substance whose broken surface is irregular. This is **quartz**. Here and there will be seen tiny, dark —even black—spots, some dull, some shiny. These are **mica**.

A little more may be found out about these three substances by breaking a chip of the granite into very small fragments. You can now pick out little pieces of each of the three and do further experiments with them. For this purpose a piece of glass and a copper coin are necessary. Using either the finger-tip, or a piece of wood, rub a small fragment of each of the three substances in turn against the glass. It will be found that only the quartz will make a scratch on the glass. Therefore it must be harder than glass, and the other two must be softer. Now using the copper coin in the same way it will be found that both the felspar and the quartz make scratches upon it, but the mica does not. The three substances therefore differ from one another in hardness.

Sometimes when granite is being quarried holes and cavities are found in the solid rock. These are lined with well-shaped

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crystals of felspar, quartz, and mica. Because of the cavity there
was room for the crystals to grow without being seriously crowded
against one another In the solid rock itself it was those crystals
which began to grow first that were free to take on their proper,
regular shapes. Those that began later had to be content to fill up
the space that was left, and so could not assume their proper
crystalline form. From what was seen in the piece of granite it is
evident that the felspar crystallized out before the quartz. Quite
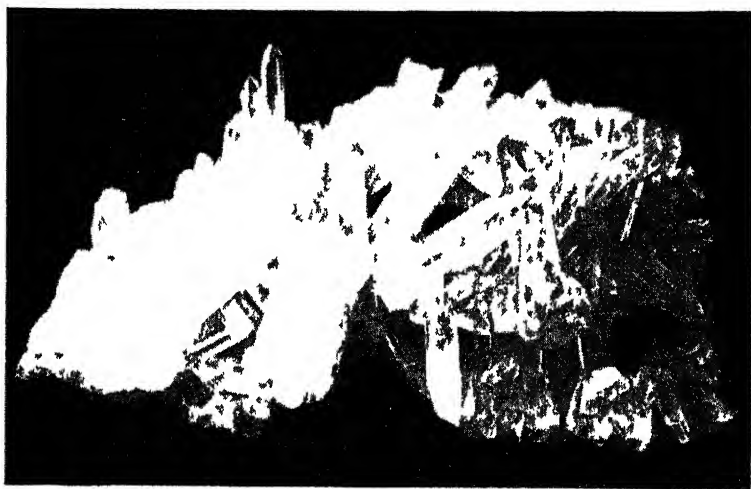
FIG 59   SILICON DIOXIDE IN THE FORM OF QUARTZ
These are crystals of the commonest substance in the crust of the earth
By courtesy of W Sutcliffe, Esq

often you will find small crystals of mica inside the large crystal of
felspar, and they must therefore have been formed first.

Rocks which consist of substances that have crystallized out on
the spot are called 'crystalline' rocks to distinguish them from
sedimentary rocks in which fragments of quartz, felspar, and even
mica also occur. In this case, however, the fragments were carried
by water to the place where the rock was formed.

Though it is a long and tedious process, chemists have analysed
these three substances. They have shown that quartz consists of
the oxide of a metal called **silicon** ; its chemical name is silicon
dioxide (Fig. 59). It has been estimated that this makes up practi-
cally 60 per cent. of the rocks and is therefore the commonest sub-
stance on the face of the earth. Only a small part of it remains free
as silicon dioxide to form quartz. Most of it plays the part of an

FIG 60   GRANITE AND THE MINERALS IT CONTAINS

In the lower line well-formed crystals of quartz, felspar, and mica are shown in order from left to right.   Above is a picture of shap granite with one surface ground flat and polished   The large crystals consist of pink felspar   In between can be seen small crystals of white felspar, irregular blebs of quartz, and small crystals of black mica

By courtesy of W Sutcliffe, Esq

acid, and enters into combination with other metals and bases. Thus felspar consists chemically of silicon dioxide combined with oxides of aluminium and of potassium, sodium, or calcium, and so is formed of silicates of these bases. Mica similarly consists of silicates of aluminium and potassium with iron or magnesium.

Granite is therefore made up of three substances—quartz, felspar, and mica—which have a more or less definite chemical composition. Such substances are called .minerals. A rock consists of minerals in varying proportions and therefore has not a

FIG. 61.   SYENITE (*left*) AND GABBRO (*right*)
By courtesy of W. Sutcliffe, Esq.

definite chemical composition. Thus some granites have more, some less, quartz ; some have potash felspar, others soda felspar.

Felspars are light-coloured minerals and, as they are abundant in granite, this is usually a light-coloured rock. Other crystalline rocks, such as **gabbro** (Fig. 61), tend to have a darker colour because they contain a larger proportion of dark, almost black, minerals such as hornblende, augite, or olivine. These also are silicates, but the proportion of silica present is much smaller than in felspar. In them the chief bases are iron and magnesium. They are therefore spoken of as ferro-magnesian silicates.

Crystalline rocks which, like granite, contain free quartz and minerals with a high proportion of silica are described as ' acid ' rocks. Rocks like gabbro (Fig. 62), which have no free quartz and

have other minerals with only a small percentage of silica, are called 'basic' rocks. Others, like **syenite,** lie between these two extremes,

FIG. 62. A THIN SLICE OF GABBRO AS SEEN UNDER THE MICROSCOPE, SHOWING FELSPAR (WHITE), AUGITE, AND OLIVINE
By courtesy of W. Sutcliffe, Esq.

and are grouped as 'intermediate' rocks. They have little or no quartz, a large amount of felspar, and a small amount of ferro-magnesian minerals.

ROCKS OF LIQUID ORIGIN

IN winter-time one way to spoil a slide is to throw salt upon it. But probably you would prefer to keep the slide and mix the salt with ice to make a freezing-mixture. Now, ice by itself melts at a temperature of 0° C., and salt at 800° C.; and yet when these two solids are mixed together they melt at −22° C. It is indeed a striking fact that two solid substances when mixed together may melt at a lower temperature than that required to melt either of the two taken alone. This fact is of great use in the iron industry, for when limestone is mixed with iron ore the stony material, or ' dross,' in the ore melts more easily and floats on the top of the molten iron which has been released. In this case the limestone is said to act as a **flux.**

The dross, which is now in reality a liquid rock, is drained off the top into iron trucks, where it is allowed to cool. Naturally it cools most quickly where it lies against the cold iron side of the truck. There it sets solid as a dark green glass. In the centre of the truck it sets more slowly and forms that greenish yellow stone we call ' slag.' Samples of both the stony and the glassy, as well as of a bubbly variety, can be obtained easily, for slag is extensively used for making roads.

Furnace slag is, then, a stone or rock which has been formed by the cooling of hot liquid. Hot liquid material occurs naturally in active volcanoes from which it pours forth as lava (Fig. 63). This eventually cools and forms rock. This liquid material is called **magma.** The rock formed by the cooling of magma is called an ' igneous rock.'

When deep borings are made into the ground, or mines are sunk to great depths, it is found that there is a nearly regular increase in temperature with depth. On the average this is about 1° F. for every sixty-four feet. The fact that magma pours forth during volcanic eruptions shows that this increase continues until the temperature is sufficiently high for some rocks to melt. It must not, however, be assumed that at great depths in the earth's crust all rock is in a liquid state. Differences of pressure and of composition also play their part and may cause the distribution of liquid rock to be quite

irregular. If only we could delve down to great depths in regions where there are volcanoes to-day we could see for ourselves just what is actually taking place far below the surface. But that is quite impossible. Are there, then, no clues to guide our imaginings? Let us see.
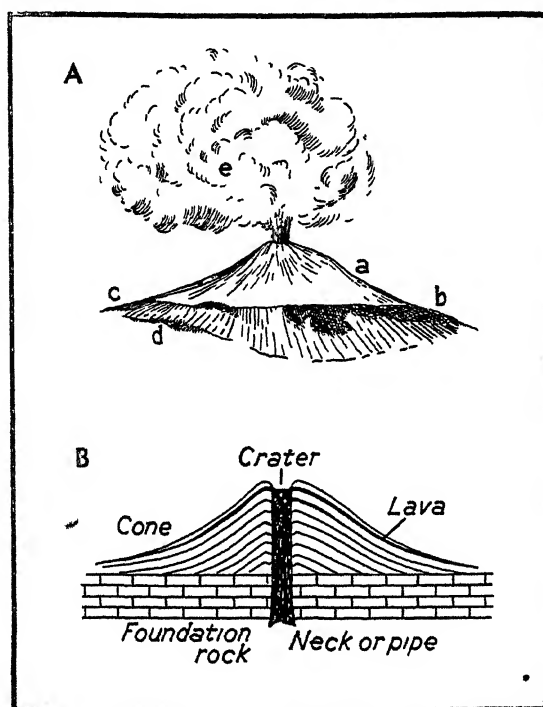
FIG 63   DIAGRAM OF A VOLCANO AND OF ITS
STRUCTURE

A, Vesuvius is shown in eruption in 1906   (*a*) newly formed dust scored by stream channels, (*b*) new lava flow, (*c*) old dust, (*d*) old lava flow, (*e*) clouds of steam   This condenses and forms the streams mentioned above.   *B*, Section of volcano, showing its internal structure

Two processes, described in earlier chapters, suggest a way of approach to the problem. On the one hand, as the result of the action of frost, rain, soil-creep (Fig. 65), and rivers, the rocks at the surface are destroyed and the waste is carried away, thus exposing the rocks below to similar destruction (Fig. 66). In due time even lofty uplands may be worn down or denuded to sea-level. On the other hand, land which is at sea-level may be lifted up to considerable heights, thus bringing still deeper rocks within

the sphere of action of the same destructive processes (Fig. 64), and so exposing to view the hidden depths in successive stages.

In many parts of the world there are regions which at one period
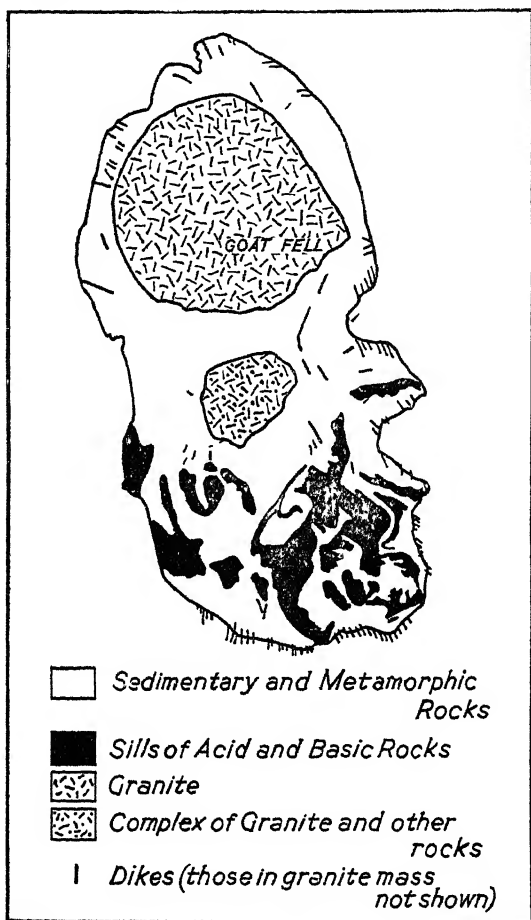
FIG. 64. MAP OF THE ISLE OF ARRAN

This map shows an area where overlying rocks have been removed to a much greater extent than in Figs. 64 and 65, so that the arrangement of more deeply seated igneous rocks is displayed.

or another were infested with volcanoes. All these regions have experienced repeated uplift and have had their rocks removed in successive slices. So it has come to pass that the older, sedimentary rocks, together with the igneous rocks formed from the magma which flowed into them, have been laid bare at different levels in

FIG. 65. GRANGE MILL, DERBYSHIRE

The hill in the foreground is the top of a volcanic neck or pipe. The ridge in the background is a limestone scarp with a lava flow imbedded between its layers. These once extended over and completely buried the neck. They have since been removed by weathering agencies.

By courtesy of A. T. Metcalfe, Esq.
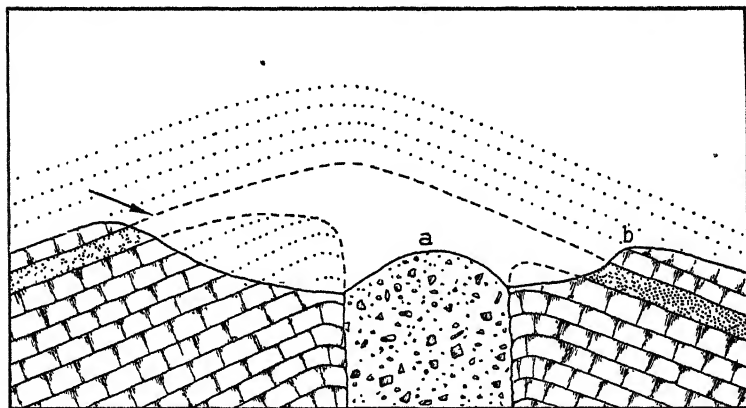
FIG. 66. GRANGE MILL: GEOLOGICAL SECTION

The arrow shows the view-point for Fig. 65. (*a*) Volcanic neck. (*b*) is the limestone scarp seen in the background of Fig. 65—its rocks enclose a lava flow. The dotted and broken lines indicate portions of the rocks that have been removed, thus revealing the arrangement of the buried igneous rocks.

F

different regions (Fig. 67). By carefully examining these bared surfaces it is possible to build up a picture of the distribution of igneous rocks deep below the surface in volcanic regions of past ages (Fig. 68). In this way a remarkably complete solution to our problem has been constructed.

Ten, fifteen, or more miles below the original surface was a great reservoir of magma, whose floor is so deep down that it has
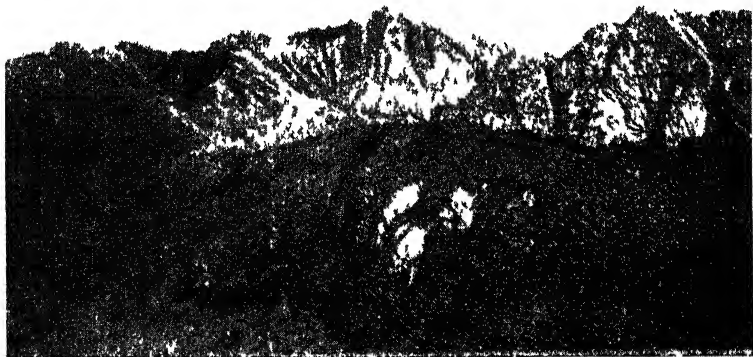
FIG 67   AN AERIAL VIEW OF GOATFELL, ISLE OF ARRAN

A mass of granite wh ch was formed far below the surface of the ground has had all the rocks which covered it removed by the action of weathering agencies. It is therefore now exposed to view, and its relationship to surrounding rocks is revealed

The present surface, with its sharp edges and peaks, has been shaped largely by the work of frost and flowing ice   The amphitheatre-shaped hollow in front of the main peak is a corrie, or cirque (p 112)

By courtesy of D J Tugby, Esq

never been exposed to view, but whose roof has been found to be very irregular in shape. The mass of rock that has been formed from this is called a **batholith**. Above its upper surface mighty vertical cracks broke through the overlying rocks and became filled with magma which set solid and formed vertical sheets of rock called **dikes** (Fig. 70). The uppermost margin of a dike is very uneven, and at one or more points penetrates yet farther up into the rocks nearer the surface in the form of cylindrical columns or ' pipes.' Some of the liquid which flowed up the vertical cracks and pipes

made its way more or less horizontally between the layers of rock, and took on shapes dependent upon the composition of the magma. When this was acid the liquid was viscous, or treacly, and did not flow far. It then formed a compact mass which bulged the rocks above it upward. Such a mushroom-shaped mass is a **laccolite**. Basic magmas, on the other hand, are more fluid. They flowed long distances between the beds of rock. The flat sheet of igneous
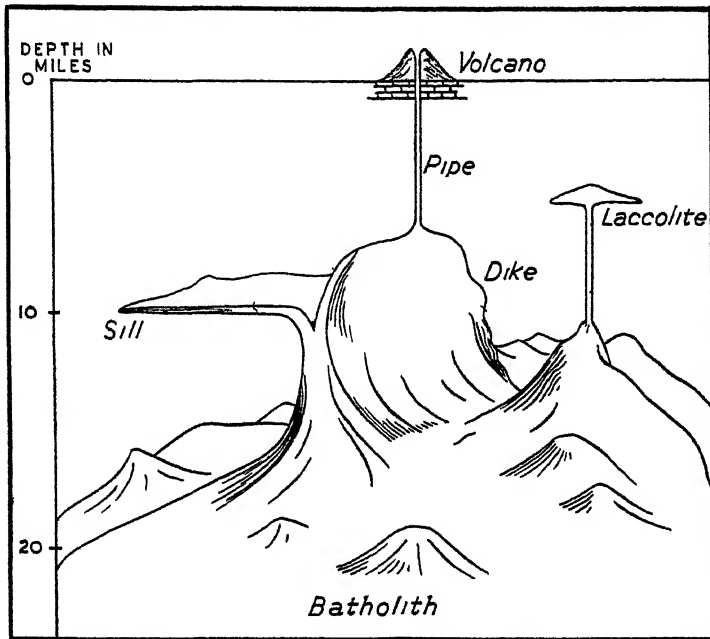
FIG 68   A DIAGRAMMATIC REPRESENTATION OF THE DISTRIBUTION OF
IGNEOUS ROCKS IN THE EARTH'S CRUST

The sedimentary and other rocks which enclose the igneous rocks are here supposed to be
quite transparent, so that the shapes assumed by the igneous material which penetrated
them can be seen

rock thus formed is a **sill**. In some cases the pipes broke through to the surface and then volcanoes came into being. Here again, the more liquid magma poured forth over the land surface or on to the floor of the sea, and spread far and wide as a thin sheet. When it cooled it set solid as a volcanic rock, usually **basalt**. For a long time similar outpourings might take place at intervals and, lying one upon another, gradually build up great dome-shaped, volcanic mountains, such as those which occur in the Hawaiian Islands in the Pacific Ocean (Fig. 71).

Among the various chemical elements which are present in the magma are oxygen and hydrogen. As the liquid ascends the pipe these gases combine and produce steam, which forms innumerable
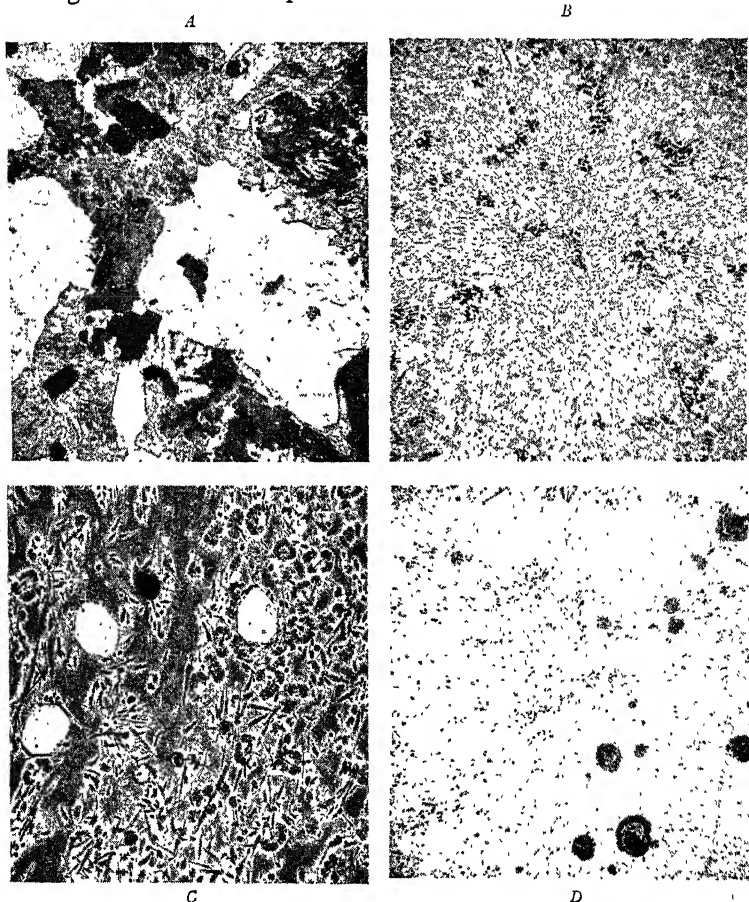
FIG. 69.   THIN SLICES OF IGNEOUS ROCKS AS SEEN UNDER THE MICROSCOPE
A, granite—consisting of large crystals; B, microgranite—consisting of small crystals; C, pitch-stone is mainly glass with three small crystals and numerous feathery embryo crystals; D, obsidian consists entirely of glass.
By courtesy of W. Sutcliffe, Esq.

bubbles in the lava. Pumice-stone is an example of a rock formed from very bubbly liquid lava. Similar bubbles also form in viscous lavas as they ascend through the pipe. In this case a scum forms on the surface of the lava in the crater. Under this a large quantity of steam accumulates, until at last it bursts with a great explosion,

FIG. 70.   AERIAL VIEW OF THE SOUTH COAST OF ARRAN

Weather and waves have removed a thick covering of rock and revealed the arrangement of a series of dikes, or vertical sheets, of igneous rock.   These are seen standing out like groynes above the beach and the water.

By courtesy of D. J. Tugby, Esq.
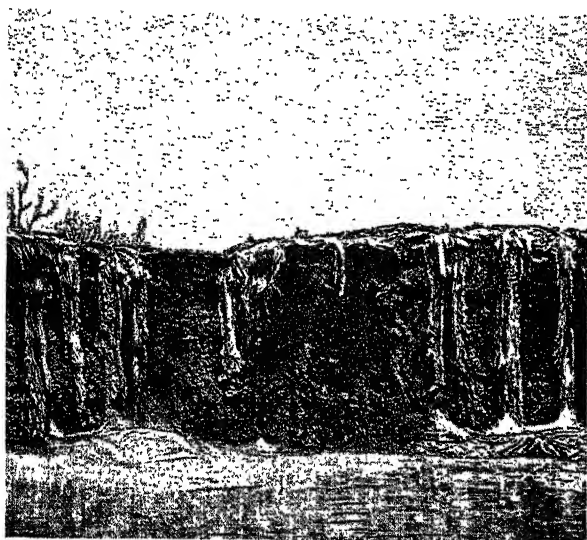
FIG. 71   HAWAIIAN ISLANDS

A lava stream falling over a cliff into the sea.

From Grabau's " A Text-book of Geology," Part I

pulverizing the scum and filling the air with **volcanic dust,** and fragments of lava. The latter fall back on to the ground in the form of clinker-like lumps, which are known as **scoriæ.** Occasionally larger masses of lava are thrown up and, since they may contain a considerable quantity of steam, explode—a fact which has gained for them the name of **volcanic bombs.** From time to time the magma wells over the edge of the crater or out through a crack in the side of the volcano and crawls slowly down the slopes as a lava-

FIG. 72.   OLD FAITHFUL GEYSER IN ERUPTION, YELLOWSTONE
NATIONAL PARK
The eruptions of this geyser occur at intervals of sixty-five to seventy-five minutes, each eruption lasting four minutes.   The height to which the column is thrown is 125 to 150 feet
From Grabau's " A Text-book of Geology," Part I
(Photo D W Johnson)

flow.   All these—lava-flows, bombs, scoriæ, dust, and fragments of rock torn from the foundations of the volcano—collect round the vent or mouth of the pipe and build up that cone-shaped mountain known as a volcanic peak.

Sometimes the vertical cracks in which dikes form break through to the surface, and then the magma coming up it overflows and may flood hundreds of square miles of the countryside.   In due time the lava cools into a black shroud, hiding from view landscapes that were once gay with flowers and trees.   Outpourings of

this type are known as **fissure eruptions**. In past ages some areas of the earth's surface have experienced such eruptions repeatedly. Layer after layer of basaltic lava have been piled one upon another in thicknesses of hundreds or even thousands of feet. Such areas occur in Iceland, the Inner Hebrides, Antrim, the Columbia Plateau of the western United States, the Deccan of India, and the Central Plateau of Africa.

With the passage of time the volcanic forces of a given region die down, and the hot liquid cools. The more deeply placed reservoirs cool very slowly, so that the molecules of different mineral substances are able to congregate in large assemblages and form crystals of the sizes seen earlier in a piece of granite (Fig. 69). Thus a coarsely crystalline rock is formed. At the other extreme the magma coming to the surface may cool very rapidly either as the result of contact with cold rock on its passage upward, or of exposure to the air. In these circumstances the processes of crystal formation may not begin at all. The liquid then sets solid as glass. In between these two extreme conditions rocks of every grade of texture may be formed, from purely glassy, through partly glassy and partly crystalline, to wholly crystalline types. The last may vary in grain from coarse to fine—as, for example, in granite and microgranite. All these grades of texture and grain are to be found among rocks of acid, intermediate, or basic composition.

Long after the volcanoes have ceased to act the temperature of the rocks beneath the area remains abnormally high. Water descending through joints and fissures becomes heated and, returning to the surface, may issue forth with the steady flow of an ordinary spring or spout up like a fountain at regular intervals. The latter are called **geysers** (Fig. 72).

INSIDE THE EARTH

HAVE you ever gone down a coal-mine ? We step into t
and feel outselves standing upon a floor as firm and safe
ground itself. The cage begins to drop, and we drop too.
a strange sensation it is—dropping, dropping freely hundreds
The cage begins to slow up and, gradually breaking our fal
us safely at the bottom. We step out, and, when our e
accustomed to the dim light, we wander along passage-w.
tunnels—some of which show bare rock above, on either s·
below us, partly hidden from view by.a framework of timb
iron girders. As we walk along our guide tells us that th
thickness of half a mile of rock above us exerting a pressure
that, if the framework were removed, the floor, walls, a
would crush inward, and in a few weeks the passage-way
be completely closed up. Broken timbers and crumpled
lying about testify to the truth of his story. Meanw.
find ourselves bathed in perspiration due, not to fright,
heat, for a multitude of observations show that the temp
increases on the average $1°$ F. for every increase of sixty-fou
depth.

All this makes us feel that we are really deep down in
earth. Nevertheless, we still have nearly 4000 miles to go
to reach the centre, and it is quite natural to wonder what :
at still greater depths to which we can never hope to penetr
even with modern boring-tools. Our experience in the min
ever, helps our imaginations a little, for if the pressure of tl
is so great and the temperature so warm at a depth of onl
mile, how much greater must they be nearer to the centr
earth. As we go through the mine we see that the rocks
jointed and cracked. Remembering the experiment w
sealing-wax, we can picture that far beneath us the rocks
plastic under the higher temperatures and the vastly
unceasingly applied pressure ; and that as the result all
fissures, cavities, and even pores become squeezed out of e>
Those depths at which all this takes place may be referred t

zone of flow in contrast with the shallower depths which may be described as the **zone of fracture.**

. There are, however, yet other sets of facts which help the imagination still further in its efforts to picture the conditions which prevail at those inaccessible depths. These are provided on the one hand by the plumb-line, and on the other by earthquakes.

If we want to make sure that a wall is quite perpendicular we
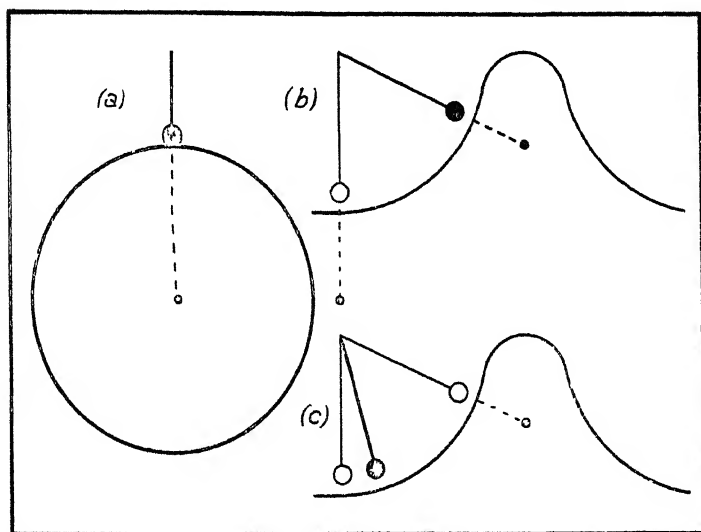
FIG. 73. DIAGRAM ILLUSTRATING THE PLUMB-LINE AS AN INSTRUMENT
FOR INVESTIGATING THE INTERIOR OF THE EARTH

(a) A plumb-line hanging over a smooth earth points to the centre of the earth; (b) a plumb-line hanging near an isolated mountain mass points to the heart of the mountain; (c) a plumb-line hanging over the earth, but close to a mountain, is attracted by both, and hangs in a position somewhere in between that shown in (a) and (b). This provides information for comparing the attractive force of the earth with that of the mountain.

use a plumb-line—a cord with a heavy weight at the end. We assume that the line drawn along the cord is perfectly vertical, that if it were continued downward it would eventually pass through the centre of the earth. Out in mid-ocean, or in the middle of a vast plain, the assumption would probably be correct; but if there happened to be a great mountain not far away it would probably be wrong, for a great mass of rock like that also attracts the weight and pulls it slightly sideways. In that case the line would not be perfectly vertical, it would no longer point directly towards the centre of the earth (Fig. 73). If the mountain stood alone, without

the earth, the weight would be pulled still farther sideways, and the line would point towards the centre of the mountain mass. In actual fact, therefore, the plumb-line hangs in such a position that the attraction by the earth is balanced by that of the rocky mountain mass. Very careful measurements of the angles made by the plumb-line with the lines which pass through the centre of the earth and the heart of the mountain make it possible to compare the strength of the attraction exerted by the earth with that exerted by the mountain.

It is natural to suppose that the attractive force of the earth would be as much greater than the attractive force of the mountain, as the earth itself is greater than the mountain. It is a surprise, therefore, to find that the attractive force of the earth is more than twice as great as it ought to be if the whole world were made of the same kind of rocks as the mountain. These rocks have a specific gravity of 2·5, which is only another way of saying that they are two and a half times as heavy as water. The stronger attractive force exerted by the earth shows that, as a whole, it is made of denser material—that, indeed, its specific gravity is 5·6. Evidently, then, the density of the earth, as well as its temperature and pressure, increases towards the centre.

Our imaginative journey to the centre of the earth is helped in a quite unexpected way by the study of earthquakes. When there is an earthquake anywhere the whole earth does, in fact, quake. At some point the rocks snap suddenly and give a shake which sends vibrations in all directions both round and through the earth (*cf.* Figs. 55 and 58). Delicate instruments record the time of arrival and strength of these vibrations when they are felt at many places in different parts of the world. Now, whether the vibration travels round or through the earth, the length of the path along which it travels from its starting-point to the instrument can be accurately calculated (Fig. 74). Assuming the rocks and their density to be the same throughout, it is also possible to calculate how long the vibration should take to travel, and the exact time at which it should arrive at the instrument (Fig. 75). In every case where the vibration has passed along a path deep down inside the earth it arrives before its time, and must therefore have travelled more quickly, and have passed through denser rocks, than those found at the surface. The rate of travel shows that the density is always greater than that of the more common rocks with which we are familiar, and that it goes on increasing with the depth.
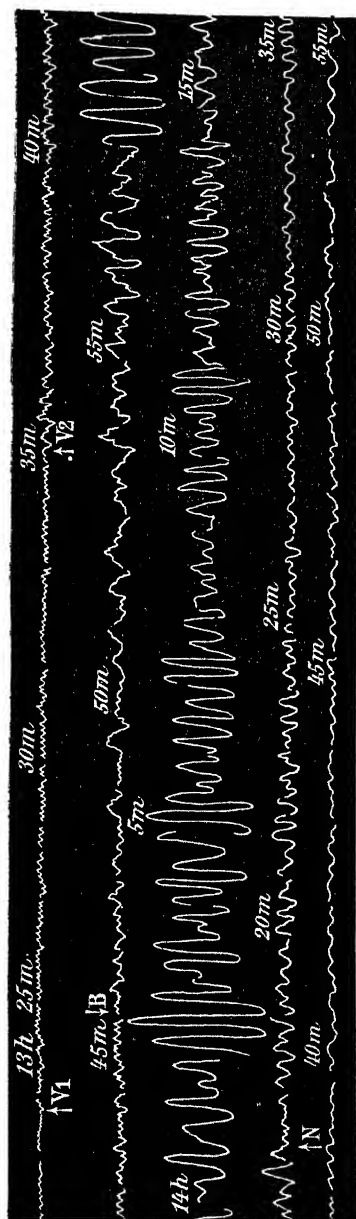
FIG. 74. A SEISMOGRAM OF THE SAN FRANCISCO EARTHQUAKE OF APRIL 18, 1906, AS RECORDED IN STRASSBURG IN ALSACE

The shocks began at San Francisco at 5 12 A.M., or at 1 12 P.M. (13 h 12 m.) Strassburg time. The preliminary record began about 13 minutes later (1 25 P.M., 13 h. 25 m.), but the main record did not begin until about 43 minutes later. The preliminary tremblings passed approximately along the path indicated in the diagram Fig 75 by the curved line next to the vertical one below H

From Grabau's " A Text-book of Geology,' Part I

(After Siebers, from Kayser's " Lehrbuch ")

The results of these earthquake studies suggest that the outer crust of the earth consists mainly of granite or rocks of granitic
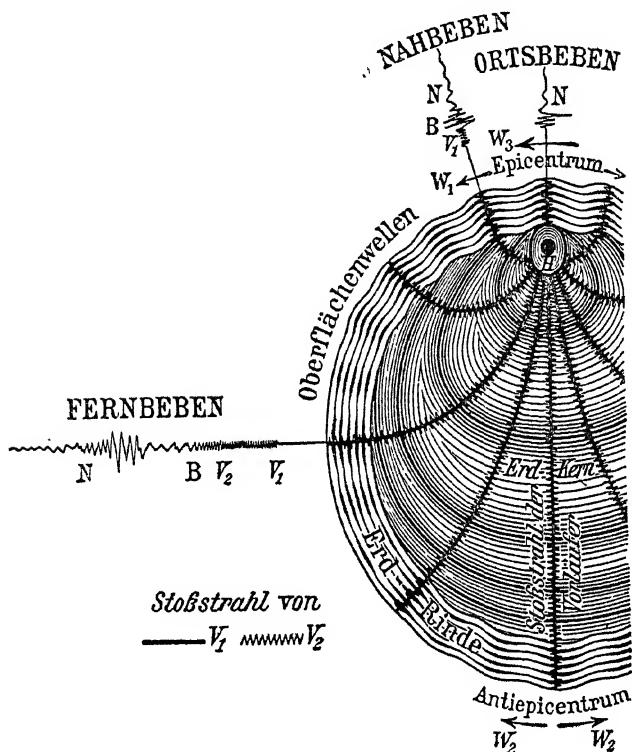
FIG. 75.   DIAGRAMMATIC REPRESENTATION OF THE PROPAGATION
OF EARTHQUAKE WAVES AND THEIR RECORD BY THE SEISMO-
GRAPH IN DIFFERENT PARTS OF THE EARTH

Erd-rinde = earth's crust ; Erd-kern = earth's core.

From Grabau's " A Text-book of Geology," Part I

(After Sieberg, from Keilhack's " Praktische Geologie ")

origin, and that the inside is made up of successive zones of more and more basic rocks, with a large core—possibly of nickel iron.

CHAPTER XIV

NEW ROCKS FOR OLD

How are bricks made ? You reply, " Out of clay." True ! but does the brick itself consist of clay ? Its colour is very different. It is much harder—so much so, indeed, that even after it has been soaked in water it can still resist strong blows with a hammer, and support great weights. During the last eighty or a hundred years brick has almost completely displaced natural stone for building houses and factories. Indeed, if it had been made by Nature and not by man you would, without hesitation, have said that brick is a rock. It is, in fact, a new rock formed from the old one—clay— partly by squeezing, but mainly by heating it to a high temperature.

In like manner, but on a much grander scale, Nature has taken large quantities of ordinary sedimentary and igneous rocks and sometimes by great pressure, sometimes by great heat, some- times by both, has turned them into new kinds of rocks—often completely changing not only their appearance but even the minerals they contain. Such rocks are called **metamorphic rocks.**

FIG. 76
FAULT-BRECCIA

*From Grabau's " A Text-
book of Geology "*

The fact that rocks are often broken or bent shows that they have been subjected to great pres- sure. Where they have been broken the masses of rock have slipped past one another. The actual plane of breaking is not always as clean-cut as diagrams seem to suggest. Often the rocks do not merely slip—they grind past one another, so that near the plane of faulting or thrusting they are smashed into fragments or ground to powder. After movement has ceased these fragments set solid to form a rock—**fault- breccia** (Fig. 76)—and the powder becomes a hard rock— **mylonite** (Fig. 77A).

Even when the rocks have been folded as intensely as possible pressure may still continue and increase. The finer-grained rocks, such as clays and shales, undergo an interesting series of changes. Each tiny particle of mineral of which they consist changes shape from the compact form of a grain to the flattened form of a penny
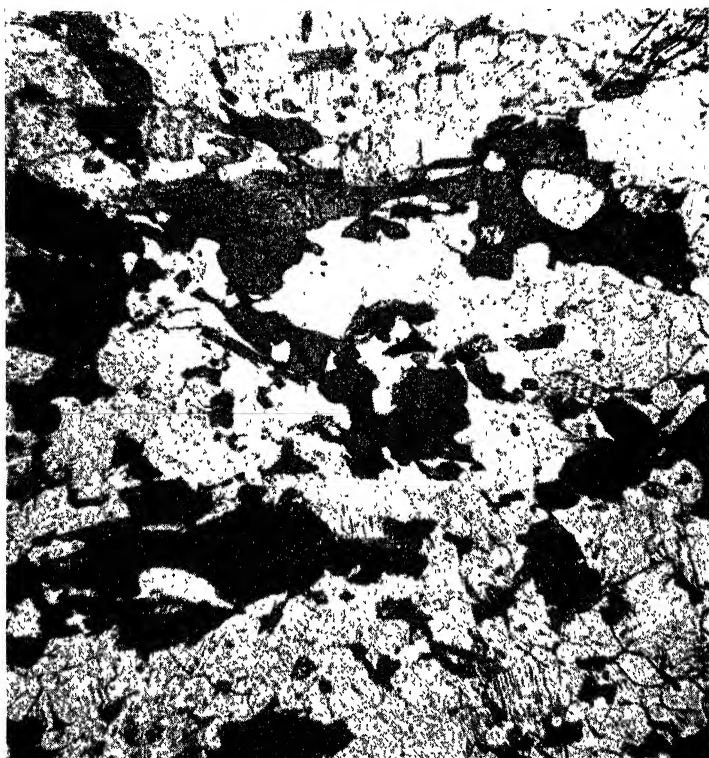
FIG. 77A. SLICES OF METAMORPHIC ROCKS: MYLONITE FROM SCOTTISH HIGHLANDS

By courtesy of W. Sutcliffe, Esq.

ICES OF METAMORPHIC ROCKS: SCHIST FROM SCOTTISH
HIGHLANDS
By courtesy of W. Sutcliffe, Esq.
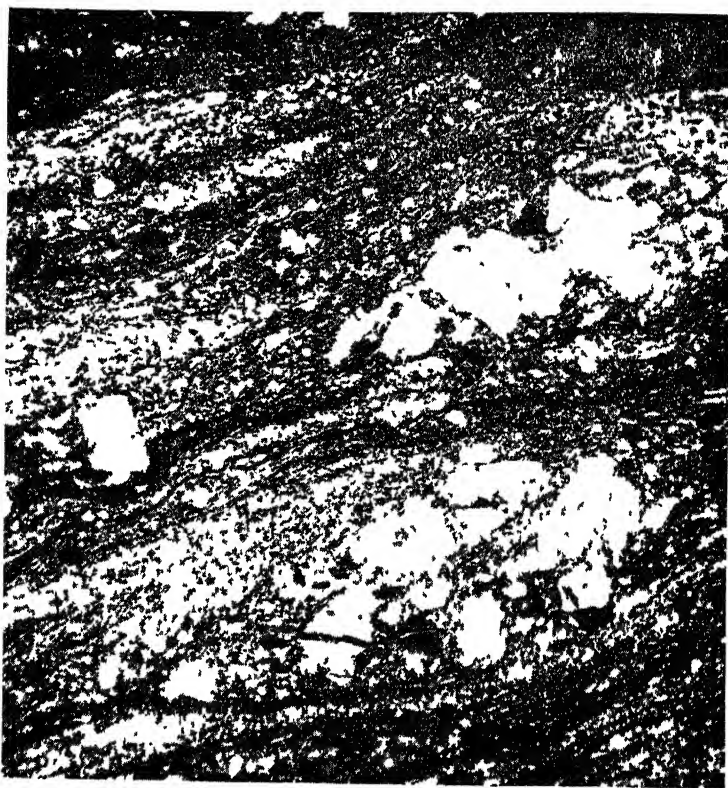
FIG. 77C. SLICES OF METAMORPHIC ROCKS GNEISS FROM SCOTTISH
HIGHLANDS

By courtesy of W. Sutcliffe, Esq.

Sometimes when you and your companions are doing physical exercises your company as a whole changes shape from a compact body marching in fours to a long line in single file. In like manner the molecules which make up a mineral grain rearrange themselves in response to the increasing pressure on the grain. The flattened particles, thus formed, lie parallel to one another in a direction at right angles to the direction of pressure. When the new rock, which has thus been formed, is broken by frost it splits most easily along the flattened surfaces of the grains. A skilled workman, making use of this fact, can split a quite large block into a number of thin plates which can be used for roofing houses.

This new kind of rock is called **slate,** and the direction of easy splitting is called a **slaty cleavage** (Fig. 78). This cleavage may have the same direction as the plane of bedding, or it may cross this at any angle. Sometimes the cleavage is only imperfectly developed. The rock then splits also along the bedding-plane, upon the surface of which fossils distorted by pressure can often be seen (Fig. 79).
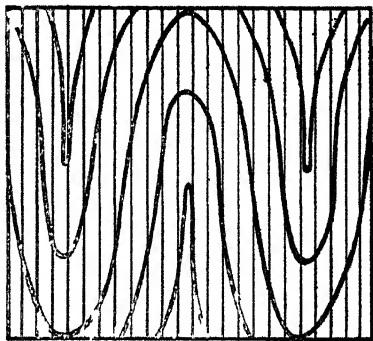
FIG 78   DIAGRAM OF CLEAVED ROCKS
Thick lines show the intense folding of bedded rocks. Thin lines show the cleavage induced by further pressure.

In Cornwall, Scotland, and many other parts of Britain and the world, masses of granite are found situated like islands in a sea of sedimentary rocks. As already seen, each granite mass was once a subterranean reservoir of hot magma which dissolved or pushed its way into and among the surrounding rocks. The heat from the magma then travelled outward, for a distance of several miles, into these rocks and changed their character. Thus a zone of new rocks was formed round the granite mass; and this is called the **metamorphic aureole.**

Starting at a point lying a little outside the aureole, let us travel towards the granite. At our starting-point the rock may be a uniformly black shale. This gradually becomes speckled or spotted with lighter patches. Farther on these have become crystals of an interesting mineral called **chiastolite,** because in transverse sections it exhibits the pattern of a cross. Continuing our journey, we find

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presently that these crystals have disappeared, the rock has become lighter coloured, and taken on a glistening, shiny look due to the appearance of a quantity of mica. The rock now breaks more or less easily into flakes. This flaky, or foliated, character of the
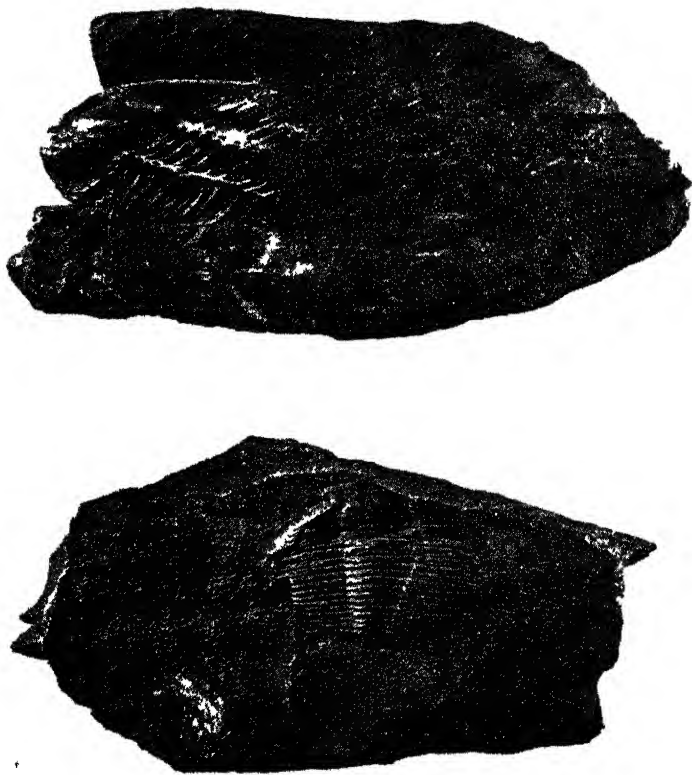
FIG. 79. FOSSILS IN SLATE

The slate has split along a bedding-plane and revealed the fossil remains of trilobites squeezed out of shape by pressure.

By courtesy of W. Sutcliffe, Esq.

rock may be seen in hand specimens, and is suggested in the name, **schist,** by which the rock is now known (Fig. 77B). As mica is in this case a noteworthy constituent the name is extended to **mica schist,** a new rock changed from the old state of a shale and a slate.

Returning to our starting-point, we may repeat the journey

along the outcrop of a belt of limestone or of sandstone. As we do so we find the limestone changing, the fossils it contains disappear, the calcium carbonate of which it consists crystallizes to form calcite, and the final result is often a beautiful white **marble**. The sandstone also changes, but not in so striking a manner. The quartz grains lose their rounded shapes and become fitted to one
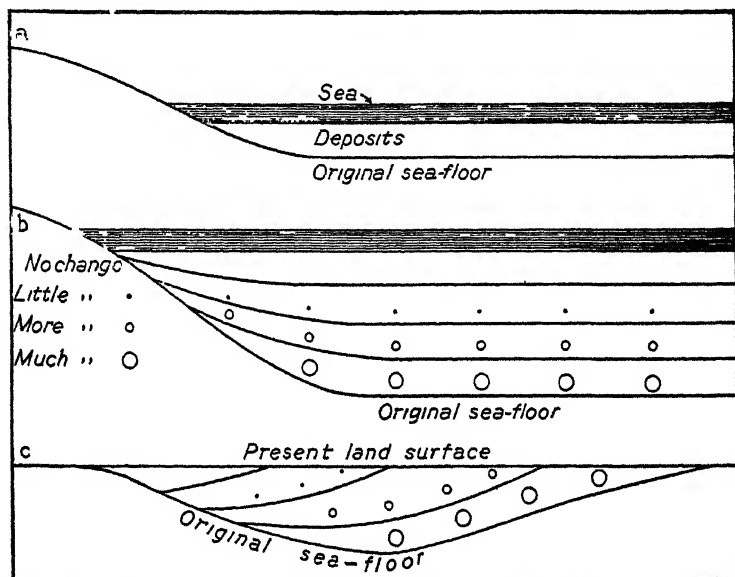
FIG 80 DIAGRAMS ILLUSTRATING REGIONAL METAMORPHISM

(a) An early stage in the accumulation of rock-forming deposits over an extensive area. (b) A very late stage in the accumulation of deposits The early deposits have sunk down to great depths, where they become subjected to high pressure and temperature. In consequence they have undergone degrees of metamorphic change which vary according to the depth they have reached. (c) As the result of movements in the earth's crust these metamorphosed rocks have been uplifted to form land, and, as the result of prolonged denudation, the various layers are now exposed at the surface.

another like tiles in a mosaic. The pores close up, and the whole becomes a very tough, slightly shiny rock called **quartzite**.

In some areas of the earth's surface sediments like sand, mud, and lime have gone on being deposited age after age, layer upon layer. As they accumulated the first-formed layers were pushed deeper and deeper down into the earth as much as five, ten, or even fifteen miles (Fig. 80). As they sank they experienced greater and greater pressures and higher temperatures. Thus it came about that enormous thicknesses of rock became metamorphosed over vast areas. In due time deposition ceased. Upward movement

now set in and was accompanied by denudation.   It c
until the upturned edges of the deeply seated rocks became
at the surface.   Journeying across such a countryside,
start out on the edge of a rock which has never been far i
surface and is therefore quite unaltered.   Thence we n
across the edges of layers that have been more and yet mor
placed.   As we do so we find an ever increasing degree o
has taken place, and the rocks pass beyond being finely cr

FIG. 81   SOME OF THE MINERALS THAT ARE FORMED IN METAMORPH
Garnet , staurolite in schist , kyanite.
By courtesy of W Sutcliffe, Esq.

schists into rather coarsely grained, crystalline rocks k:
gneiss (Fig. 77C).   This usually has a texture similar to
granite, but unlike that it shows the same flaky arrangeme
minerals as we have already noticed in schist.

These changes are accompanied by the appearance
minerals in an orderly sequence that corresponds to the c
temperature to which the particular layer of rock has been st
In those layers which were less deeply placed, brown mica, o:
is common.   In those more deeply placed, **garnet,**

staurolite, and **sillimanite** appear in succession (Fig. 81), thus reflecting the sequence of increasing temperatures and pressures to which the rocks have been subjected.

Other new minerals may appear according to variations in the original composition of the rocks. In addition to garnets these include such gem stones as rubies, sapphires, and emeralds.

Vast areas of metamorphic rocks—gneisses and schists—often penetrated by mighty masses of granite and other igneous rocks, lie exposed to view around the Baltic Sea and Hudson Bay and form the heart of the various continents. At their margins the rocks of these areas pass beneath a covering of sedimentary rocks formed at a later date and laid down upon them. Metamorphic rocks, therefore, provide the foundations of every great continent.

THE HARVEST OF THE ROCKS

IRON, gold, zinc, lead, copper, aluminium—these are all metals highly prized by man. All are widely scattered through the waters and the rocks, like wheat over a cornfield. Now, if wheat is to be used it must first be separated out by threshing it from the straw, and winnowing it from the chaff. Nature has her own ways of threshing these metals from the rocks, but she usually leaves the winnowing to be done by man.

Iron is present almost everywhere in the rocks (see Fig. 8).
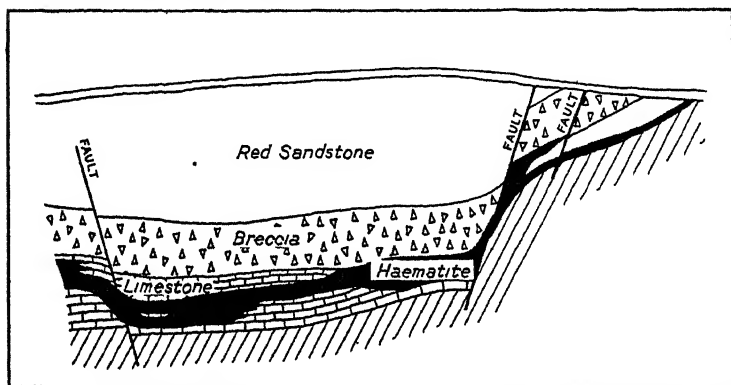
FIG 82   A SECTION BASED ON RECORDS COLLECTED FROM IRON-ORE MINES
IN CUMBERLAND

Adapted from the Geological Survey

In the form of iron oxide it clings as a fine dust to the surfaces of the grains in sandstone or of the tiny particles in clay. Its presence gives a bright red colour to the rocks over large areas of country in the Midlands of England and elsewhere, and to the soils of tropical lands. In like manner, as iron sulphide, it is responsible for the grey, blue, and black tints of many kinds of rock.

Nevertheless, these rocks cannot be used by man as sources from which he can obtain iron, for the proportion of metal in relation to useless material is so small that the cost of extracting it would greatly exceed the value of the iron thus obtained. But Nature, unlike man, need not take account of time and labour. Her workers never faint, neither do they grow weary. Day in,

day out, year after year for long, long stretches of time they go on working. Water percolating slowly down through soil and rock dissolves minute quantities of that iron-oxide dust (Fig. 82). As it journeys on it may come to some beds of limestone. Here it makes an exchange: it dissolves some of the lime from the rock, and in return lays down its tiny load of iron oxide. As more water comes flowing along the same path, load is added to load until large
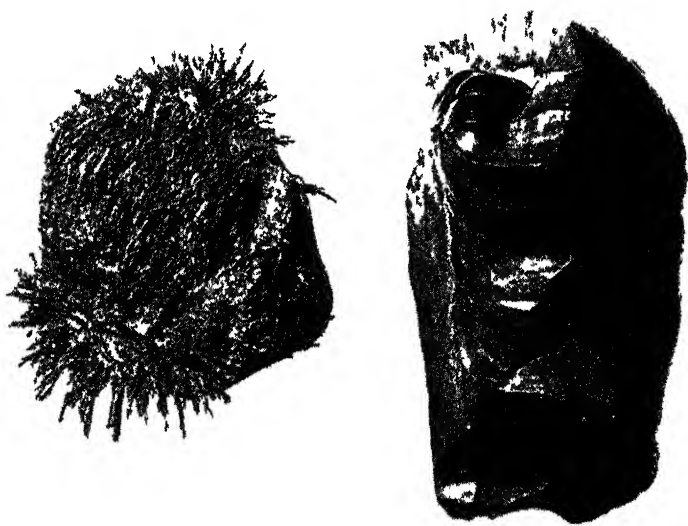
FIG 83   TWO IMPORTANT IRON ORES

Left, magnetite, or magnetic iron ore   Iron filings have been sprinkled on the specimen   These have arranged themselves along the magnetic lines of force emanating from the ore. The possession of magnetic properties gained for the ore the name of " lode stone "

Right, hæmatite, showing the kidney-like appearance of its surface   The broken edge at the top shows the radiating arrangement of the fine, needle-like crystals of which the mineral is built.

By courtesy of W Sutcliffe, Esq

quantities of iron ore have, so to speak, been threshed out of the rocks and gathered together in this one place. Then comes the miner. He removes the ore and sends it to the blast furnace, which is man's device for winnowing away the chaff, or more correctly the ' dross,' and separating out the iron.

The kind of ore thus formed is called **hæmatite**, and consists of red iron oxide. It frequently occurs in lumps, rather like a sheep's kidney in appearance, and is consequently often known as **kidney ore** (Fig. 83). **Limonite** is a similar ore, but it is brown in

colour, and consists of hydrated oxide of iron. The broken surfaces of both kinds show that they are made up of delicate, needle-like crystals lying side by side and arranged in a radiating fashion. Another type of ore, called **ironstone,** consists of iron carbonate. It was formed in a different way and occurs in layers interbedded with rocks of various ages. Iron sulphide occurs in similar layers. It is also found in the form of little round balls or of beautifully shaped crystals. These have a bright surface and a yellow colour not unlike that of some kinds of gold. Because it has often been mistaken for this it is commonly known as ' fool's gold.' Its proper name, however, is **iron pyrites** (Fig. 84).

Aluminium, in the form of alumina or aluminium oxide, occurs in clay in much greater abundance than does iron. Here again, before man can use it Nature does much preliminary threshing. Her procedure, in this case, is the reverse of that described above, for this time it is the unwanted substances that percolating water removes, and the wanted substance—the aluminium oxide—that is left behind. The ore thus formed is **bauxite,** a most valuable source for the extraction of aluminium.

For the next part of our story we must, in imagination, leave the surface of the earth and plunge down to those depths where the great granite masses, already described, were born. Our starting-point must be that very early stage when the space now occupied by granite was filled with hot magma, a complex liquid containing the atoms and molecules of many of the metals which chemists have discovered. Some of these—silicon, aluminium, potassium, sodium, calcium—were relatively abundant. Others— tin, copper, zinc, lead, gold—were scarce. In addition, this liquid also contained large quantities of oxygen, hydrogen, and smaller quantities of carbon dioxide, chlorine, fluorine, boron, and sulphur.

As the temperature of the liquid lowered crystals of magnetic iron oxide formed. In basic magmas these congregated together in large quantities, and thus provided an important source for another iron ore, called **magnetite.** In acid magmas there formed felspar, quartz, and mica, which filled up most of the space with solid but still hot crystalline rock. Thus the more abundant metals, which make up these minerals, were removed from the solution ; and the rarer metals were gathered together in the small amount of liquid that remained. As the rock cooled it began to shrink, and cracks were formed which extended deeper and deeper into the granite and farther and farther out into the sedimentary rocks around.

The residual liquid, as it may now be called, was squeezed out of the granite into these fissures. Meanwhile pressure diminished, and the gases 'and vapours dissolved in the liquid bubbled out and escaped along the fissures. Some of them penetrated into the granite on either side and produced various chemical changes in
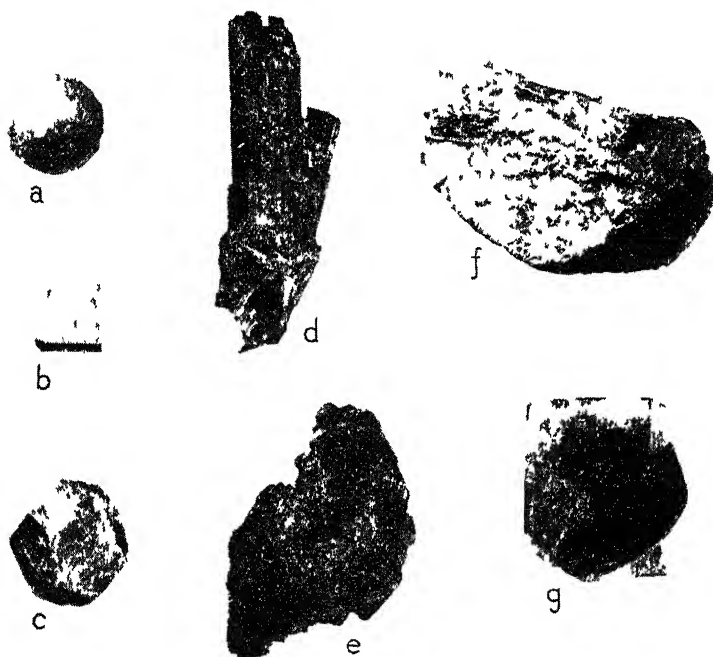
FIG 84   SOME COMMON MINERALS

(a) A spherical nodule of **marcasite** which consists of iron sulphide, (b) and (c) two crystals of iron pyrites which also consist of iron sulphide, (d) some crystals of **tourmaline**, consisting of boro-silicate of aluminium; (e) a cluster of crystals of **galena**, or lead sulphide, (f) a lump of **copper pyrites**, or copper sulphide, (g) two crystals of **fluor spar**, composed of calcium fluoride

By courtesy of W Sutcliffe, Esq

some of its minerals. Among the most striking of these was the action of the carbon dioxide and the water vapour formed from the hydrogen and oxygen. These converted large quantities of the felspar into **kaolin** or china clay. In like manner the fluoric acid produced **fluor spar** (*cf*. Fig. 84), the boric acid **tourmaline**, and the two together, **topaz**.

Other vapours and gases reacting on one another formed metallic compounds which crystallized out along the sides of the fissures in a more or less regular succession, from below upward :

cassiterite or tin oxide, copper pyrites, zinc blende, galena or lead sulphide—all of them valuable metallic ores (*cf*. Fig. 84). In the final stages, and with still lower temperatures, superheated water passed along the fissures and into their many ramifications, carrying with it much silica still in solution. This crystallized out and formed veins of milk-white quartz, and sometimes clusters of beautiful rock crystals (*cf*. Fig. 59). Occasionally these final exudations from the magma contained gold, which, in a metallic condition, was deposited among the quartz.

Those same processes, which ultimately removed the covering of sedimentary rocks and exposed the granite mass to view, also laid bare these fissure or mineral lodes, and thus placed them within the reach of man—for him to collect the ores and winnow out the metals. During the destruction and removal of the outer part of the granite and of the rocks surrounding it the waste material was carried away by rivers and streams. Some of the metals, like the gold, and the metallic ores, like the tin oxide, that effectively resisted the rotting action of air and water were likewise carried away. They, however, were heavier than the other waste and were not so easily lifted and carried along. They therefore tended to lag behind the other waste and to accumulate in hollows in the bed of the stream. Thus the flowing water winnowed the unwanted waste away and formed concentrations of the heavier, more valuable minerals in what are called **placer deposits**. It was in such situations that man first found gold and tin.

As a mineral lode approaches the surface it comes within the zone of influence of rain-water soaking down into the ground. The sulphides of zinc, lead, and copper then become chemically altered—mainly into carbonates, which are carried in solution down to the level of the water-table. There they are redeposited, with the consequent enrichment of the vein at that level. It is hereabouts that a number of beautifully coloured ores are formed, such as the royal blue **azurite** and green **malachite**.

AN UNTIDY WORKER

THE definition of a tidy worker is one who has a place for everything and keeps everything in its place. Now, flowing water is a tidy worker, for, though it picks up and carries or rolls along a jumbled load of mud, sand, pebbles, and even boulders, it sorts these out from one another and deposits them in an orderly fashion —first the coarse and then the finer sediments—on the sea-floor.
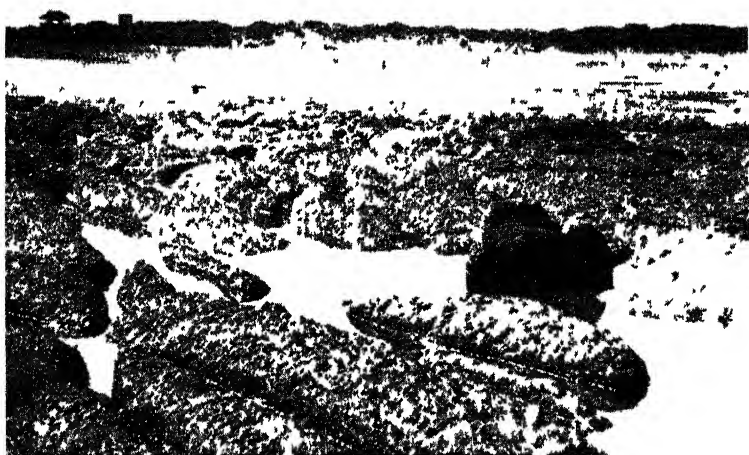
FIG 85. BOULDER CLAY FORMING PART OF THE BEACH AT CHAPEL ST
LEONARDS, LINCOLNSHIRE

Imbedded in the clay may be seen numerous pebbles, stones, and boulders derived from various kinds of rock and brought by ice from the North of England, Scotland, and even Scandinavia.
Photo H. H. Swinnerton

At many places in Great Britain, North-west Europe, and other parts of the world the rocks which make up the countryside are buried under a covering of deposits that can only be described as a jumbled mixture of boulders, stones, gravel, sand, and mud. A common name for these deposits is **boulder clay**, or till (Fig. 85). From the soil of a ploughed field good collections of many different kinds of rocks can be made—granite, gneiss, schist, flint,

chalk, and so on. When these are examined some are found to be identical with the rocks which underlie the boulder clay. Others can be matched only by rocks found in far-away districts.

This boulder clay is just as untidy in its distribution. It may be spread in extensive sheets over lowland country. There, quite often, the rivers and streams have cut through it and into the rocks beneath. The remnants of the clay have therefore been left as cappings to the hill-tops. Elsewhere, in more hilly and mountainous country, it is found forming low, crescent-shaped mounds, lying like crude dams across the valley floor. On the downstream side of the mound this floor is covered by an apron-like sheet of gravel and sand, containing pebbles and stones identical with those in the boulder clay, and evidently derived from the same source. Here, however, they have been sorted out, presumably by the action of water.

A close inspection of the stones in the boulder clay shows that many of them have had their angles rounded off, and their surfaces smoothed and often marked with scratches. With all these facts in mind, we go up the valley in search of other clues, and it is not long before we notice here and there, sticking up through the soil of the pastures, clumps of rock which, in striking contrast to the jagged rocky edges which outline the hill-crests, are rounded off and are sometimes scored with scratches (Fig. 86). The sight of these raises our suspicions that the untidy worker was one that could hold stones in its grasp and use them for grinding and scratching the rocks beneath (Fig. 87).

FIG. 86.
ICE-SCRATCHED
STONE
From Grabau's " A Text-book of Geology," Part I

Nowhere in the British Isles is there any natural agency that does its work in this fashion, and the question arises : is such an agency to be found elsewhere to-day ? Fortunately the answer is yes, and it comes from the mountains of Switzerland and Norway. There, as we travel up the valleys, exactly the same features are to be seen repeated at successive stages. At the last stage we find the crescentic dam of boulder clay banked against the lower end of a glacier. Here is the agency we are looking for. That agency is **ice.**

The uppermost parts of the valley, and the ground beyond them, are so high above sea-level and the temperature is so low that

v which falls in winter is never completely melted in the
. It has, therefore, been piled up year after year to a depth
reds of feet.   Under the pressure of the upper layers the
ones become compacted into ice, and the whole glides
lown the valley.   Overlooking it on either side are the
es and steep slopes of the mountains.   The rocks of these
ıg gradually shattered into jagged surfaces by the frost,
ıe loosened stones and boulders go tumbling down on to
ace of the glacier below.   There on its margins they form
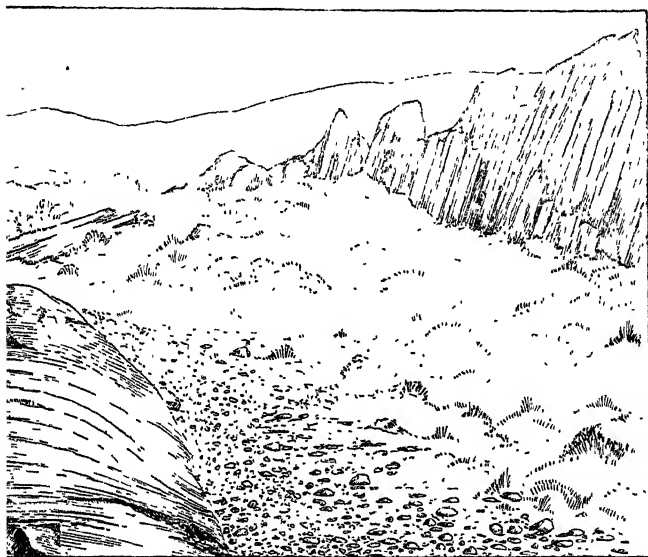
G. 87.   GLACIATED AND FROST-SHATTERED ROCKS, GALWAY
ıded by the grinding action of ice armed with stones and sand are seen in the left
nd.   Others, shattered by the action of frost, occur in the background on the right.

aps, or **lateral moraines** (Fig. 89).   Some of this debris
vn into the great cracks, or crevasses, which appear in the
of the glacier and become buried in the ice itself.   Some of
her with other blocks plucked from the rocks in the floor
sides of the valley, are gripped by the bottom layer of ice.
glides along, like a giant file, it grinds against the rocks
, scooping out the softer portions and rounding off and
ng the projecting harder portions.
ıe lower end of the glacier the ice melts.   On the whole the
of ice brought to this point balances the loss by melting,
the end, or 'foot,' of the glacier remains at a standstill.

Meanwhile the stony debris, brought by the ice, is released and dumped on the ground in the form of a crescentic heap, the **terminal moraine** (Fig. 88). The water formed by the melting either flows directly off the ice or, dropping down the crevasses, runs along tunnels underneath it, and ultimately escapes beyond the moraine as numerous streamlets. These spread their burden of gravel and sand on the ground in the form of a sheet, known as the **outwash apron.** The water then gathers together into a river and carries the finer sediments yet farther afield.
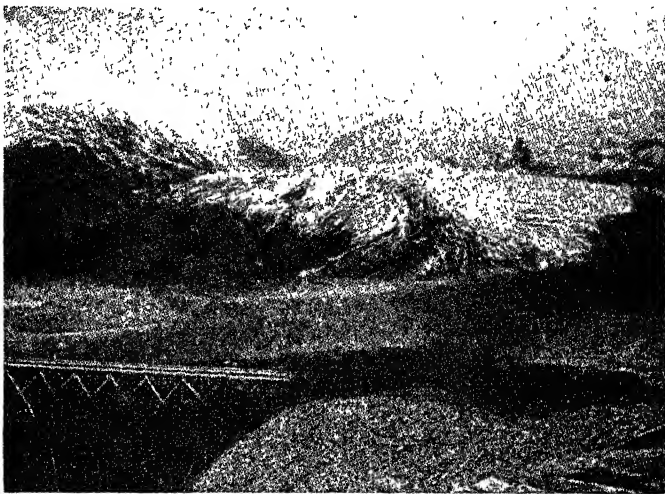
FIG. 88.   SPENCER GLACIER, ALASKA
This is melting back and shows a sloping front and a well-developed terminal moraine,
especially on the left.
From Grabau's " A Text-book of Geology," Part I

Glaciers are sometimes described as rivers of ice. Now, rivers have tributaries flowing in from tributary valleys. At first sight the glacier seems to have no tributaries, for it is hemmed in along much of its course by steep, often almost precipitous, valley sides. High up, however, glaciers may be seen in small valleys which end abruptly near the top of the slope (see Fig. 89). These are called **hanging valleys,** and the glaciers lying in them **hanging glaciers,** presumably because they look like pictures hanging on a wall. How did they come to be up there? In the main glacier the ice is much deeper than it is in these side glaciers; it therefore exerts much greater pressure on its bed and, by grinding the rocks more rapidly, wears the floor of its valley below the level of the

FIG. 89.   THE ALETSCH GLACIER, SWITZERLAND

Bands of moraine are seen on both edges and along the middle of the glacier. On the right it dams the mouth of a small valley which is in consequence occupied by a lake (the Marjelen See). Note the U-shape of the main valley, the small hanging valleys with glaciers high up on the right, and the jagged skyline carved by frost action.

floor of the tributary valley. One striking feature about this is that the glacier deepens its valley most rapidly not at its foot but in its higher reaches. When, therefore, the glacier finally disappears the deeper hollow thus formed becomes filled with water and produces a lake. Lakes of this type are common in Wales, and in other mountainous regions, where the presence of moraines and scratched rocks shows that glaciers once worked there.

The ice of a glacier, as it flows along, plucks the rocks at its margins and so widens the valley floor. In so doing it undermines and removes the tips of the spurs and the corresponding portions of the tributary valleys. Thus the main valley acquires, in transverse section, the characteristic shape of the letter U, with a broad floor and steep sides made up of truncated spurs and valleys (see Fig. 20).

Tracing both main and tributary valleys to their sources, it is found that many of them end abruptly in amphitheatre-like hollows on the mountain sides. These features, known as **cirques** or **corries,** owe their existence to the action of the ice, at the head of the glacier, in plucking the sides and grinding the floor (see Fig. 67).

ROCKS AS CLOCKS

A CLOCK has two uses : it tells us how many hours we have been working or playing, and it tells us the precise minute when we started or finished. But we do not always think in terms of hours and minutes. We speak of the time when we shot a goal, the time of sunset or sunrise, the time when we fell off a bicycle. We are then using events, and not figures on a clock-face or dates in a calendar, as indicators of points of time. The geologist, in like manner, talks about the time when the forest that is now submerged was growing on dry land ; when the waves were splashing on the beach that is now raised.a hundred feet above sea-level ; when warm seas, dotted with coral islands, covered the area we now call Derbyshire. That forest, that beach, that coral sea, like the figures on the clock-face, represent definite times. There is one great advantage about a clock : it has the hours numbered in order— 1, 2, 3, and so on up to 12—so that if you are told to be on the football field at 2.30 P.M. you know that the game begins after 2.0 and before 3.0. But which came first—the forest, the beach, or the coral reef ? It is interesting to know that events have happened, but it is still more interesting to know the order in which they happened. Is there any time-scale by which we can record the sequence of events in the earth's story ? This is a problem we must now try to solve.

We saw earlier that the soil brought down by rivers to the sea, and the waste from the destruction of the cliffs by the waves, are spread out like a great carpet on the sea-floor. As storm follows storm, year in year out, new carpets of gravel, sand, and mud are laid down one upon another. The succession of carpets marks succession of time as surely as the figures on a dial. The bottom carpet was laid down first, the top carpet last. Each carpet in its turn represents a brief period of time.

Slowly the sea-floor rises and becomes land. The carpets made up of various deposits turn into rocks, which make the land. Each carpet becomes what is called a layer of rock, or **stratum**, and the series of strata represent a series of brief periods of time, beginning with the bottom stratum, which represents the first of these periods of time, and ending with the top stratum, which represents the

H

last (Fig 90)   So whenever you see in a quarry or a cliff-face a number of layers of rock you are looking at part of the geologist's clock-face   We can imagine that each layer represents a geologist's minute   But what a minute !

Here and there in the country there are great brick-works   The

FIG 90   CHALK CLIFFS, FLAMBOROUGH, YORKSHIRE

Each layer, or stratum, of rock represents a definite, though short, period of time during which it was being made   The bottom layer represents the earliest and the top layer the latest of those periods   The boulder clay resting on the ground above was formed later still   The face of the cliff with its caves has been cut by the sea since the boulder clay was laid down   Thus most of the details in the scene are figures on the geological clock face

clay for these is dug out of extensive pits twenty, thirty, or more feet deep.   Scattered about the floor of the pit are often many shells that have been removed from the clay.   These show that the clay was once mud upon the sea-floor   That mud settled slowly as fine dust out of the undertow.   In calm weather there would be little or no dust.   In rough weather there would be quite a lot.   How long would it take for the dust to settle, form mud,

and stiffen into a layer of clay a foot thick? A day? A week?
A month? A year? Ten years? You cannot answer with
certainty That is why a geologist does not like talking in terms
of years, and is content to answer " Quite a long time." But the
pit was thirty feet deep, so we must multiply that long time by
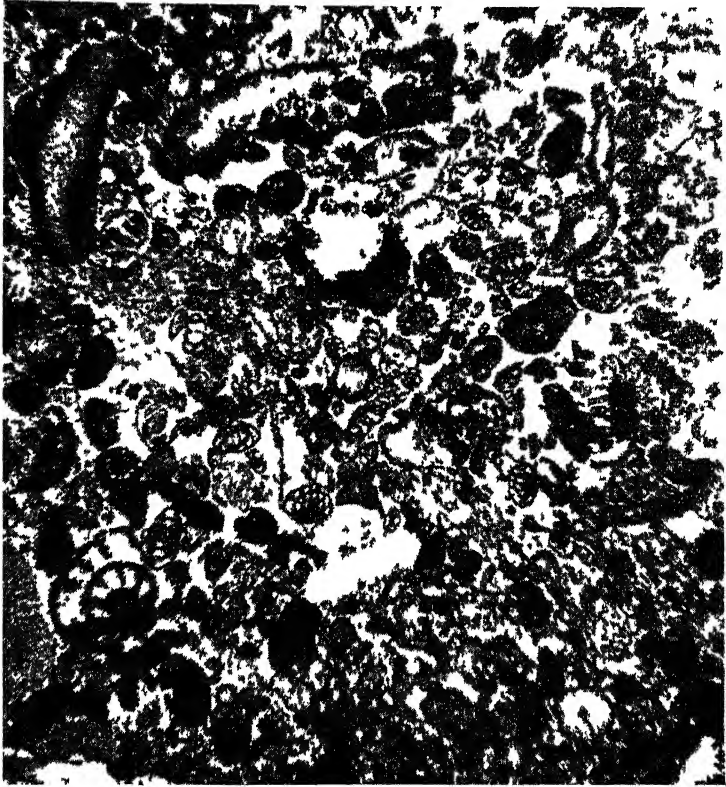
FIG 91   A THIN SLICE OF DERBYSHIRE LIMESTONE (GREATLY MAGNIFIED)
In it are many minute coiled shells (foraminifera)   Between them are broken fragments of
other and larger shells   All these are cemented together with crystalline calcium carbonate
or calcite
By courtesy of W Sutcliffe Esq

30, or by 600, for that is probably the total thickness of all the
layers of clay in that district when taken together. Yes, when we
stop to think thus, the length of time required does make one gasp.

The layers of limestone in Derbyshire are sometimes made up
mainly of corals, sometimes mainly of ordinary sea-shells, sometimes
of tiny shells (Fig 91) no bigger than the head of a pin.

Think of a sea-shell that is no bigger than the shell of a garden snail. How long does a snail live? How long does it take to make its shell? You don't know. If you look at one carefully you will find marks which show that it usually takes more than three years. Suppose the sea-animal took that amount of time to make its shell. Having made it, the creature dies and leaves the shell on the sea-floor. How many generations of these creatures would have to live and die in order to cover a bit of the sea-floor with shells and thus form a layer about an inch thick? Five? Ten? Twenty? You cannot say, you can only answer " Quite a number." Multiply the number you select by three and you will realize that an inch of
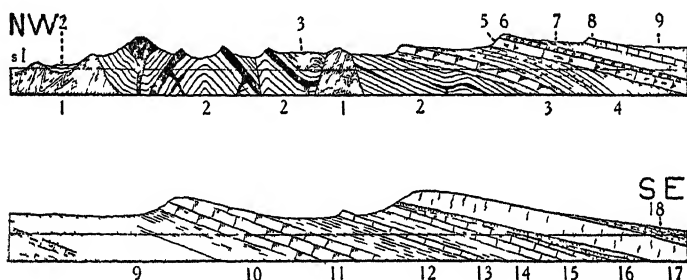

FIG 92   GENERALIZED SECTION FROM MENAI STRAITS (NORTH WALES),
ACROSS ENGLAND TO ESSEX

This shows the relationship to one another of the layers of rock which form the foundation
of the country. Their main grouping according to the eras when they were formed is
as follows (1) Pre-Cambrian , (2–8) Palæozoic , (9–17) Mesozoic , (18) Cainozoic. See
also the sketch of geological time in the frontispiece

From Grabau's " A Text-book of Geology," Part II

limestone represents quite a long time. But the limestone in Derbyshire is more than 1700 feet thick, and must, therefore, have taken a vast period of time in the process of being formed.

If a deep trench were dug across England and Wales from Essex to Anglesey its sides would show the cut edges of many layers of rock overlapping one another (Fig. 92). A drawing of the side of the trench would give us what is called a **geological section** across the country. This section shows that the last-formed, or youngest, layer is in Essex, and that the first-formed, or oldest, is in Anglesey. Each layer in its turn comes up to, and is exposed at, the surface. This exposed part is called its **outcrop.**

If these layers were slipped over, one on top of another, they would make a pile, or geological column, about twenty miles high. Such a column is called a ' vertical geological section.' What

length of time does that column represent? That is a poser! With the help of students of physics other more complex but more reliable means have been devised for arriving at an estimate of time than those we have been discussing. By these it has been estimated that the figure would be in the neighbourhood of six hundred million years. Geologists think of that time as being divided into four main parts—like morning, afternoon, evening, and night; but they call their divisions **Pre-Cambrian, Palæozoic** or Primary, **Mesozoic** or Secondary, **Cainozoic** or Tertiary, and Quaternary respectively. That ending ' zoic ' is our old friend the word ' zoo ' in another form. ' Palæo ' signifies ancient, or old-fashioned; ' caino,' recent, or new-fashioned; and ' meso ' is betwixt and between the other two.

The very brief period during which man has existed on the earth is, in our eyes, so important that it has received a separate name, Quaternary or Post-Tertiary.

These great major divisions of geological time are subdivided into numerous smaller ones, like the hour, minutes, and seconds of the clock-face. In this geological time-scale names and not numbers are used. The table in the frontispiece gives the more important of these divisions and their names.

WILLIAM SMITH

WILLIAM SMITH, like Charles Lyell, was one of the founders of the science of geology (Fig 93) Born in 1769, he died in 1839, and therefore lived at a time when the making of canals and bridges was vital to the rapidly developing industrial life of England In order to do his work as a surveyor and civil engineer efficiently and speedily, he gave much careful attention to a study of the nature and arrangements of the rocks The bearing of this upon his work becomes obvious when it is recollected that a canal traversing clay country would give less trouble from leakage than one crossing an area of sandstone

It is, of course, quite easy to discover the nature of the rocks in districts where there are brick-pits, quarries, and sea-cliffs in which the rocks themselves can be seen But over most of the countryside the rocks are hidden from view by a thick mantle of soil Sometimes the nature of the soil gives a clue to the kind of rock that lies beneath As shown earlier, however, soil may travel from its birth-place and come to overlie rocks of a different character from the one in which it had its origin Such difficulties merely test the ingenuity of man.

FIG 93 WILLIAM SMITH ONE OF THE FOUNDERS OF MODERN GEOLOGY

From Grabau's A Text book of Geology Part I

How, then, has he overcome this one ? Just as the shape of your hands and face, though covered with skin and flesh, reflects the arrangement of the bones within, so the shape of the surface of the ground gives clues to the nature and arrangement of the rocks beneath. On the whole, where the rock is hard, it will not be so quickly broken and reduced to soil by frost and other agencies as soft rock. The latter will provide more soil more rapidly for removal —by rain-wash, soil-creep, and rivers—than will the former The

THE CLAY PLAIN WHICH IS SEEN FROM THE CREST OF THE SCARP
SHOWN IN FIG 94

surface of the softer, or less-resistant, rock will be lowered more
speedily than that of the harder rocks, which will consequently be
left projecting to a higher level, possibly forming a range of hills
(Fig. 94). Since the shape of the ground reflects the nature of the
rocks beneath, the line along which the surface changes from a
gentle to a steep slope must lie close to the boundary which
separates the outcrop of the less from that of the more resistant
rock (Fig. 95).

William Smith had a keen eye for changes in the character of
the soil, and in the shape of the ground, and could read rapidly the
information which clues of this kind revealed about the arrangement
of the rocks underground. Skilled as a surveyor, he was able to
plot these boundaries upon a map. His first attempts at this kind
of work were made for the country around his home, near to the
city of Bath. Having mapped the outcrops of the rocks in that
district in this way, he painted them different colours, and thus
produced the first geological map.

Geological mapping, however, is not always quite so simple,
for other difficulties often present themselves. As we have seen,
a sheet of deposits on the sea-floor consists in one place of gravel,
in another of sand, and elsewhere of mud. The layer of rock formed
from that sheet will, therefore, change from resistant sandstone in
one district to perishable clay in another. The question then
arises : what are we mapping ? Are we mapping the rock or the
layer ? Merely mapping the rocks give us little further information
than we have already learnt in the quarry. On the other hand,
mapping the layer opens up broad new fields of inquiry into the
arrangement of the layers, and the underground structure of the
area (Fig. 96). A strip of colour on a geological map, therefore,
represents the outcrop, or area, occupied by rocks of the same age ;
and one such area may include several different kinds of rocks—
limestone, sandstone, shale. The lines upon the map represent
the boundaries between rocks of different ages.

When making such a map it is not always possible to follow a
given boundary throughout the whole of its course. The surface
feature that has been the guide may disappear for various reasons.
The resistant sandstone may give place to clay, or it may be buried
under some later rock whose outcrop trespasses across that of the
one that is being followed. At some distant place this trespasser
may be present no longer ; how then can we be sure that the rock
now outcropping at the surface belongs to the layer that we are

studying ? William Smith found the clue to the solution of this difficulty in the fossils that were imprisoned in the rock. By carefully collecting and comparing fossils from layers of different ages he discovered that each set of rocks of one age contained fossils that were peculiar to itself (cf. Figs. 4 and 5). If, therefore, the rocks in two quarries, far distant from each other, yield the same fossils it is safe to assume that those rocks are of the same age.
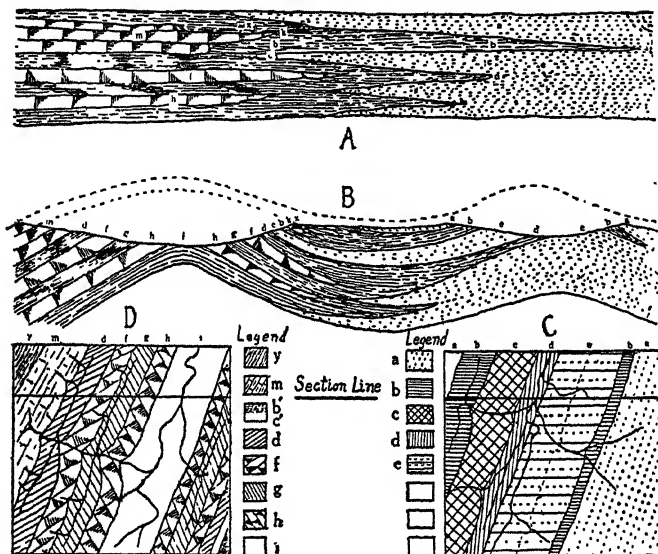

FIG. 96. DIAGRAMMATIC MAPS AND SECTIONS

(A) Section showing how rocks of the same age may change from limestone to clay or sandstone when traced from one place to another ; (B) is the same section after the layers of rock have been folded and then partly worn away ; (C) and (D) are geological maps of parts of the same region. Though the rocks shown in the two maps differ a good deal, they nevertheless belong to the same original layers and are of the same age.

From Grabau's " A Text-book of Geology," Part II

Having overcome this and other difficulties, William Smith set out to make a geological map for the whole of England and Wales. This he completed and published in 1815 (cf. the coloured endpaper map). In doing this work he travelled as many as 10,000 miles in one year. Bearing in mind that this was before the coming of railways, we cannot but be amazed at his energy and enthusiasm. This map shows that England is like a ragged scrap-book of the past. The layers of rock are like pages with edges torn and centres destroyed, thus exposing to view portions of the pages below. The detailed characteristics of the rocks, and the fossils they contain,

are the ' scraps ' which give picture-peeps of the conditions which prevailed in this part of the world when that layer of rock, that page of the scrap-book, was being formed. Similar maps have since been made for many other parts of the world.

With the geological map in your hands you have a guide that will show you where to go in order to find rock formed at any period of time you wish to study. In one corner of the map is an index. This is given in the form of a geological column or vertical section, and shows the scheme of colours used and the order in which the layers of rock they represent were formed, beginning with the oldest at the bottom and the youngest at the top. At the side of the column the names of the successive divisions of geological time are given. In the following pages the story of some of the events which happened during these bygone periods of time will be reconstructed, with the help of the clues which we have up to this point been studying.

RECONSTRUCTING THE STORY

CHAPTER XIX

THE EARTH IN CHILDHOOD AND YOUTH

llow of the Royal Society of Mars came on a scientific
on to this earth for two months to study the growth and
nent of human beings it would seem at first sight that he
n set an impossible task, for to watch the whole of the
s of growth he would have to live here three-score years

How, then, would he go about his task in the very short
his disposal ? Being observant, he would soon notice in
ets women pushing perambulators and little children
beside them. He would see boys and girls running home
ool, young men and women parading the pavements, and
digging in gardens. He would study examples of each on
mption that they represented typical stages in the growth
an being.

, our world is only one in a group of bodies we call the
tem. In the centre is the sun, and around it other worlds,
ts, circulate. Some of these, like Venus and Mars, are
e the earth ; others—for example, Jupiter and Saturn—
t balls of gas or vapour. The sun itself is the same, but it
that it supplies all the light and heat for each of the planets,
much larger than all of them rolled into one. All this,
with the fact that the earth is hot inside, suggests the idea
earth was also once a vaporous globe like Jupiter, and that
till it may have shone, by reason of the intensity of its own
'hat this was so no one has lived long enough to prove, but
erally believed that about 10,000 million years ago our world
ally like that.

1 our imaginations, we naturally try to penetrate yet farther
nd we ask, " How did this solar system, with its central
revolving planets, come to be ? " Here again the discoveries
y astronomers help us. Deep in the starry skies their great
es have revealed the presence of mighty clouds of very

transparent but slightly luminous gases, popularly known as ' fire mist.' These **nebulæ**, as they are called, are not all alike, but differ from one another in ways which suggest stages of change or growth.

Furthermore, just as we learned much about the interior of the earth by studying earthquake vibrations and waves, much also has been found out about these nebulæ and other heavenly bodies by a study of the light that comes from them. The facts thus gathered indicate that in its early stages the nebula was irregular in form. Gradually its substance moved towards its centre in a spiral path, and became concentrated into a ball that rotated like a top. The speed of rotation, however, became so great that this ball became flattened at the poles and bulged considerably at the equator. Sometimes two of these bodies passed relatively close to each other, and the force of attraction between them drew out portions of the bulge into long, tongue-shaped tidal waves. While the tips of the waves travelled outward their bases continued to rotate rapidly with the central ball and thus the waves became more or less spirally coiled (Fig. 97). The substance of the waves was not, however, uniformly distributed, but became concentrated into masses or knots of various sizes. In due time the central ball became the sun ; and the knots the planets. One of these became our earth.

Such was the state of our earth 10,000 million years ago. Once more it should be noted that no one can possibly prove this story to be true. It is to be regarded as one reasonable interpretation of the facts observed by students of the stars.

Strictly speaking, this part of the mystery of the earth's story does not come within the scope of the science of geology. Nevertheless, there comes a stage in that story when the astronomer hands over the responsibility to the geologist, saying, " You carry on where we leave off." The geologist thus has handed over to him a globe in which, at first, all the rocks and minerals we have been studying were in a gaseous state. Gradually the heat of this globe was dissipated out into space, and as it cooled much of the gaseous material became first liquid, then solid. Meanwhile the heavier substances, sinking towards the centre, formed that heavy core we have already noted, called the **barysphere** : the lighter, rising to the surface, formed a stony rind of igneous rocks, the **lithosphere.** It should be noted that separation of the heavier and lighter was never completely effected.

For a time the rind was still so hot that when at last rain began to fall from the sky it boiled away rapidly into steam. Ultimately the crust cooled, and water was able to lie upon the ground and fill the hollows; so the seas and oceans were born. Some of the gases never cooled to a liquid state, but have remained to this day as the air we breathe—the atmosphere. Rivers and streams now
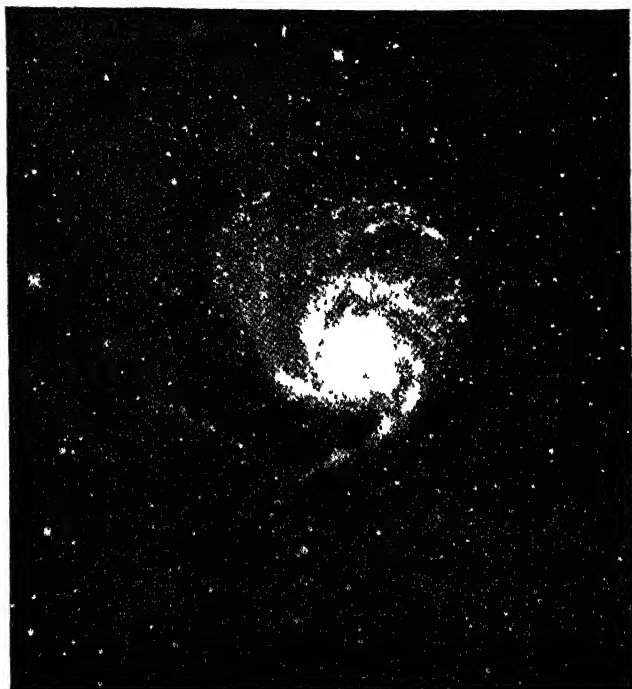

FIG 97. SPIRAL NEBULA IN THE CONSTELLATION URSUS
MAJOR (MESSIER 101)
This was taken with the two-foot reflector at the Yerkes Observatory.
From Grabau's " A Text-book of Geology," Part II

flowed over the ground, carrying the waste from the destruction of the rocks and depositing it in hollows on the land and on the floors of lakes and seas. In due time these deposits became the sedimentary, or stratified, rocks. The astronomer's part of the story was ended, the geologist's had begun. The period covered by the latter is called **geological time.**

The oldest rocks known to geologists have all been metamorphosed, a simple statement of fact which means a great deal.

It tells us that probably no part of the original igneous crust of the earth can be seen at the surface to-day. It tells us that those original rocks were extensively destroyed, their waste piled up into mighty thicknesses of sedimentary rocks, large portions of which became metamorphosed on a regional scale. As already seen, these rocks occupy extensive areas of the continents, and form the foundations upon which all later rocks have been laid down.

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THE SECRET OF THE ALPS

For the study of really great mountain ranges we must travel to the Alps, the Himalayas, or the Andes. The Swiss Alps are, however, most widely known, for they have been a popular holiday resort for several generations (*cf.* Fig. 89). Among the visitors have been many geologists for whom it has been no more than a busman's holiday. Their efforts, together with those of geologists living on the spot, have resulted in the gradual accumulation of a multitude of facts about the rocks of the Alps and about their arrangement. Out of the confusion facts have emerged which fit into one another like the pieces of a jig-saw puzzle. To-day we begin to see the
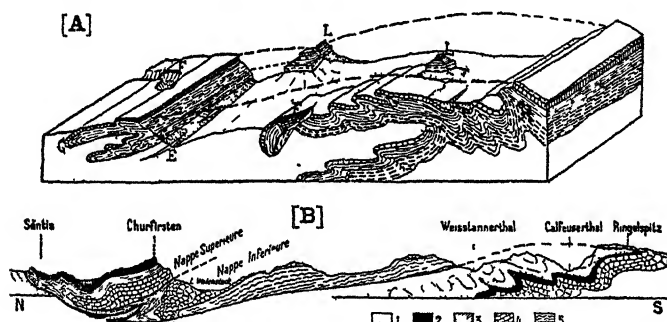

FIG. 98. BLOCK DIAGRAM (*A*) AND SECTION (*B*) ILLUSTRATING
OVERTHRUST IN THE ALPS
(*After Lugeon*)
From Grabau's " A Text-book of Geology," Part I

main outlines of the picture they form, and it is seen to be one of amazing complexity.

No two pieces of the jig-saw are exactly alike, but most of them show rocks that have been squeezed and folded intensely. In some the folds are relatively simple. In others they are frilled and overlap one another. Others again show reversed faults and portions of great thrust-planes. Gradually the relationships of the pieces and groups of pieces to one another have been solved, and a general picture of the structure of the Alps as a whole has been reconstructed (Fig. 98).

This great mountain system is seen to consist, in its broad

northern portion, of giant recumbent folds which have, as it were, fallen over towards the north.   Among them are titanic masses that have been sliced through and thrust forward for miles in the same direction.   Along the southern flanks of the system is a narrower portion of similar structure, in which the movements of folds and thrusts have been in the opposite direction.   The upper part of the picture cannot, of course, be seen to-day, for it has long since been destroyed by the action of rain and frost, rivers and glaciers.

Sometimes you pick up a crumpled piece of paper and, for reasons of your own, pull out its edges, smooth out its wrinkles, and restore it to its original flat condition.   That is what some geologists have done to this general picture showing the structure of the Alps.   To-day this system of mountains is only 150 kilometres (90 miles) wide from north to south; but when its folds are flattened out, and its thrust-masses slipped back to their original stations, its sheets of rock spread out into a belt not much less than 1200 kilometres (720 miles) wide.

Those sheets of sedimentary rock, being largely of marine origin, were deposited in a sea referred to as ' Tethys.'   This lay, like the Mediterranean, between the continental masses now known as Europe and Africa, but was of much greater extent.   With the Alps must be associated the Atlas Mountains, the Pyrenees, and all the great ranges stretching eastward through Asia Minor and the Himalayas to the East Indies.   Tethys was, therefore, much wider and longer than the Mediterranean.   It continued in existence from late Palæozoic, throughout Mesozoic, into early Cainozoic times.   All that time rock-waste from the adjoining continents was being carried into its waters, and accumulating in great thicknesses upon its floor (Fig. 99).   The earlier-formed sheets were thus pressed down to profound depths, and underwent metamorphism on a regional scale, but the later-formed layers became normal sedimentary rocks.   Meanwhile the margins of the land masses on either side moved with gentle see-saw movements, now sinking more deeply below sea-level, now rising to become land.   In association with these movements the coastlines migrated to and fro, and fresh rocks were from time to time plastered on to the continental fringes.   A broad, long strip of the earth's surface, such as that occupied by Tethys and serving as an area of deposition for a vast stretch of time, is known as a **geosyncline.**

But up-and-down movements were not the only ones experienced

ntinental masses.   Like giant rafts, they appear to have
rthward across the face of the globe.   The African mass
have drifted a little more quickly, and thus gained upon
ean mass.   In consequence of this the rigid under-portion
r of Tethys was broken by reversed faulting and squeezed
rower space.   At the same time the thick accumulations
s forming the upper part of the floor became folded, at
 gently.   The intensity of the pressure increased towards
of Mesozoic times, and attained its climax in the middle
ainozoic era.   All this was accompanied by thrusting
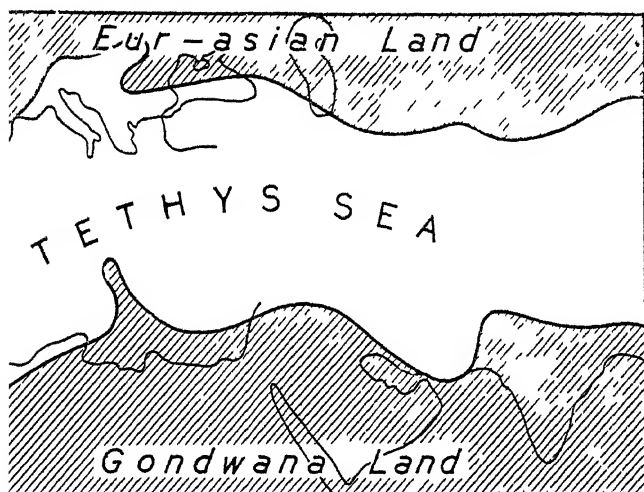
FIG. 99.   MAP OF TETHYS
e name given to a long, relatively narrow sea which occupied a great geosyncline
     lying between the two major land masses of primeval times.

ng of ever-growing complexity.   In this way the Alps,
ther mountain systems with which they are linked, came
g.
is general picture of events two main features stand out
tly.   On the one hand are the vast rigid areas lying north
1.   On the other is the weak belt which, under the increas-
 sank continuously until eventually, in response to lateral
 it became squeezed into a smaller space and, at the same
e to the lofty altitudes of a mountain system.   Other parts
ust of the earth show the same two types of feature.   It
herefore, that the architectural pattern of the world's
 made up of ' stable blocks ' separated by ' mobile belts.'

.

Some idea of the arrangement and position of the mobile belts may be gained by tracing out on a map the courses of the greatest mountain systems. If this is also marked with red dots where volcanoes occur, and green dots for places subjected to earthquakes, it will be found that a remarkable close relationship exists between the distribution of mountain systems, volcanoes, and earthquakes.

Within the meshes of the network pattern made by mobile belts lie the stable blocks. Most of these are situated in the continents, but one large block occupies the site of the Pacific Ocean.

If some portions of the earth's crust have been squeezed and folded it is natural to suppose that others have been stretched and their parts torn asunder. The Atlantic and Indian Oceans, which do not conform to the pattern of blocks and belts described above, exhibit characteristics which suggest that there is also a third element in the design that may be spoken of as ' areas of fracture.'

"THE SECRET OF THE HIGHLANDS"

of the Highlands "—such was the title of a paper
he great English geologist Charles Lapworth (Fig. 100).
nds referred to were the Highlands of Scotland. The
evealed was that the rocks there had been mightily
.d intensely folded, over-folded, and broken by thrust-
mpressive as those in the
in fact; in Scotland there
l to view the worn-down
l roots of what had once
intain range whose peaks
to the sky to heights as
those in any range in the
y (see Fig. 54).
est rocks involved in these
rements were laid down, in
zoic times, as deposits in a
icline extending in a north-
ection along the margin of
in stable block. The move-
those which produced the

FIG 100. CHARLES LAPWORTH
*From Grabau's " A Text-book of
Geology," Part II*

ie Himalayas, began almost
ily; then they gradually
i intensity, and ultimately attained a climax about the
he Palæozoic era, and resulted in what is known as the
mountain system (Fig. 101). These mountains occupied
the region now called Scotland but also the northern
England, Wales, Ireland, and most of Norway.
ier did this growing mountain system appear above the
se in height above the adjoining lands, than Nature
ttack it with all her destructive agencies; the waves
ts fringes, frost and rain scoured the whole of its surface,
ind running water removed the waste and dumped it
ands and on the floor of the sea.
ing time the rate of uplift exceeded that of destruction,
iountains maintained their place among the grander

features of the earth's surface. Eventually lateral pressure weakened; folding, fracturing, and uplift ceased. Destroying agencies now gained the upper hand ; valleys were deeply excavated and widened ;
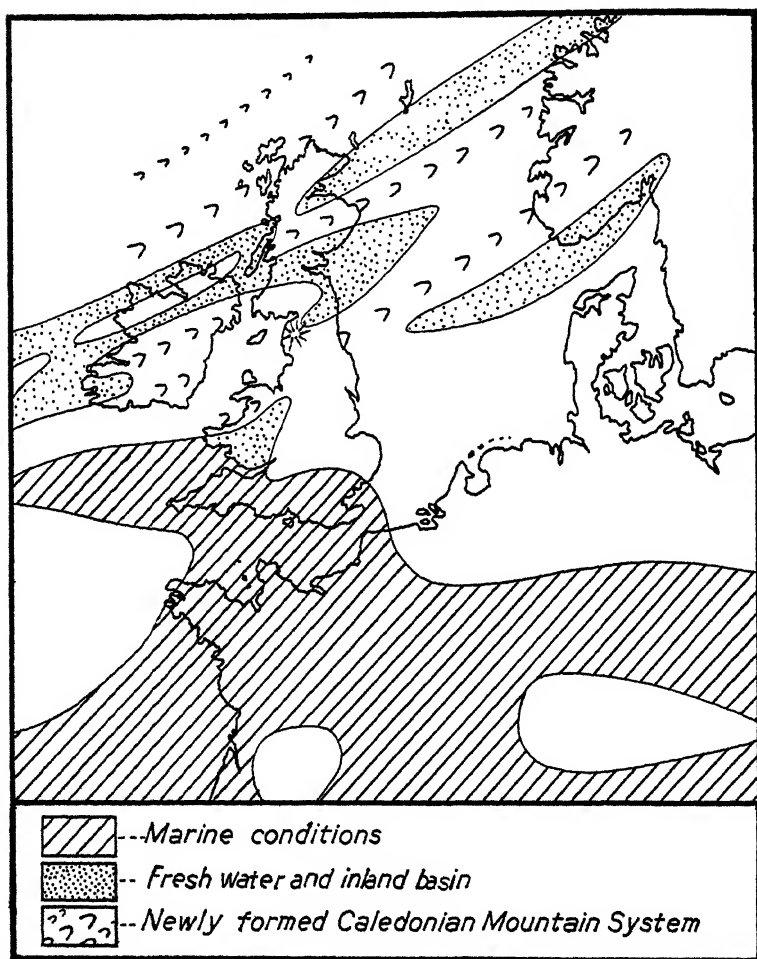

Legend:
///// ---Marine conditions
:::: -- Fresh water and inland basin
?? -- Newly formed Caledonian Mountain System

FIG. 101. WESTERN EUROPE IN OLD RED SANDSTONE TIMES

the mountains which separated them were laid low. Thus the whole mighty system was worn down almost to sea-level, and its roots were exposed. In the lowlands thus formed were wide vales traversed by slow, meandering rivers and separated by gently rising ground of low altitude. Such a lowland is called a **peneplain**.

difficult to realize that this impressive sequence of
ιired a vast period of time for its completion (Fig. 102).
ormer part of this period uplift, not only of the folded
lt, but also of a portion of the adjoining regions, was
During the second part the wearing processes developed
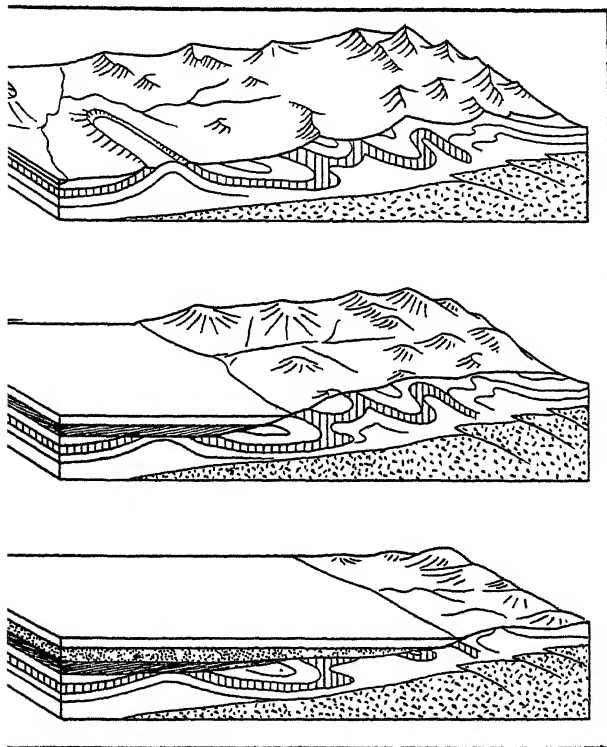
)CK DIAGRAMS TO ILLUSTRATE THE CHANGES WHICH TAKE
PLACE DURING A GEOLOGICAL CYCLE

.ge during which denudation of the land is dominant. (*b*) The middle stage.
ιow far advanced, and relief features are less prominent. The sea has sliced
e lowlands. The waste from the destruction of the land has been laid down
ιor. (*c*) A late stage. The land has now been reduced almost to a plain, the
ns of which have been inundated by the sea. On the floor of this the deposits
seen lying unconformably upon the eroded edges of the older rocks.

ιm, and were automatically accompanied by the removal
te, and the deposition of this in extensive sheets on the
ln the third part those gentle movements reflected by
ιs as submerged forests set in, and the sea transgressed
ιow very spacious lowlands. Hence these now became

reception areas for sediments, the layers of which rested upon the worn-down, or truncated, edges of the older rocks. Such a local relationship of younger to older rocks is called an **unconformity** (Fig. 104).

This vast sequence of events, here given in outline, is known as a **geological cycle**, and ranged over a length of time comparable in magnitude with 100 million years. The cycle just described commenced about the middle of the Palæozoic era and was completed towards its close. This cycle affected at least a large portion of the European area. It may have occurred simultaneously all over the world, but as yet the evidence for this is not conclusive.
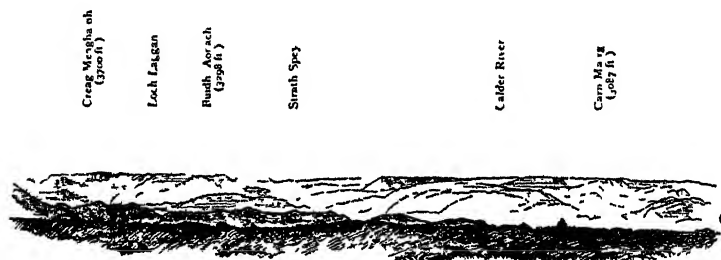
FIG 103. HIGHLAND PLATEAU
This is a view from Dalwhinnie looking westward.
From " The Scenery of Scotland," by Sir Archibald Geikie (Macmillan)

Similar cycles also took place in other parts of the world, and over other stretches of time. Some of the latter must now be described.

The very ancient rocks which make up the Outer Hebrides, the seaboard of the North-west Highlands of Scotland, and the extensive shield lands around the Baltic and Hudson Bay and elsewhere, all display the worn-down roots not merely of one but of several great mountain systems which came into being during pre-Cambrian times. These may be referred to collectively as having been formed by Huronian movements. If, as seems not improbable, each of these mountain-building movements was the beginning of a new geological cycle, the mere thought of such a series of repetitions creates an overwhelming sense of the magnitude of the length of time labelled by this one word—pre-Cambrian.

At the close of the Palæozoic another cycle was opened by the coming-on of the Hercynian mountain-building movements. The system produced had two main branches, which converged and united in central France (cf. Figs. 122 and 133). The roots of the Armorican branch form the upland plateaus of Cornwall, Devon,
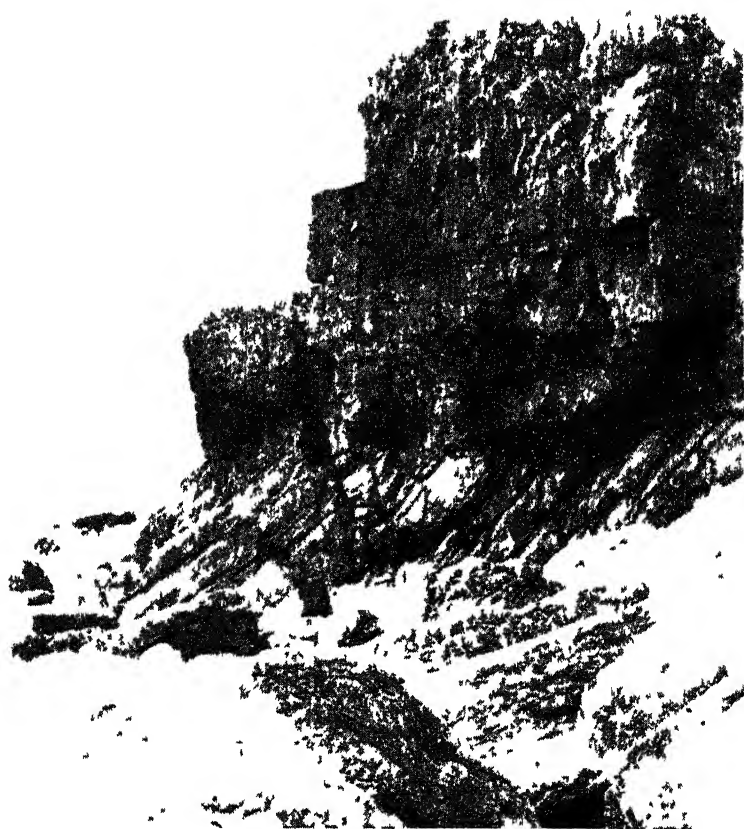
FIG. 104. UNCONFORMITY, GLAMORGAN COAST

This photograph shows mesozoic rocks (liassic) resting upon the eroded, upturned edges of Palæozoic rocks (carboniferous).
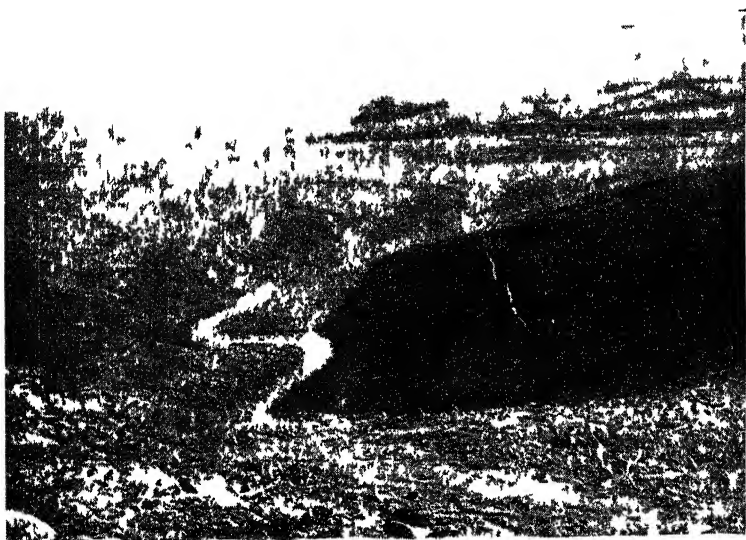
By courtesy of J. H. Wilde, Esq.

FIG 105   DARTMOOR DEVONSHIRE

Peneplained surface of granite uplifted to form a plateau with a general altitude of more than 1500 feet is shown here   Note the long, gentle slopes of the skyline and the very broad, open valley in the middle distance   In the floor of this a narrower valley has begun to appear in association with the rejuvenation of the river Tavy

Photo H H Swinnerton

FIG 106   THE RIVER TAVY, DARTMOOR

The valley of the Tavy is here seen more deeply incised into the plateau   It shows all the char acteristics of a youthful valley—viz , steep, convex sides , narrow floor , and bouldery bed of the stream

Photo H H Swinnerton

and Brittany   Those of the Variscan branch are seen in the plateaus of Bohemia and the Ardennes

The succeeding phases of this new cycle lasted throughout Mesozoic times and were brought to a close by the Alpine and associated mountain-building movements   These, in their turn, introduced yet another cycle, which we are now experiencing and which is now probably entering its second phase

The existence of raised beaches and submerged forests along our own and other coastlines reminds us that the main trend of a

FIG 107   NORTH OF ST DAVID S, PEMBROKESHIRE

This shows the characteristically peneplained surface, at an altitude of 200 to 300 feet, which in some parts of Wales lies between the coast and the loftier inland plateau   Such a marginal surface is called a platform   In the background are two residual hills, or monadnocks

Photo H H Swinnerton

geological cycle may be interrupted or emphasized locally by movements of uplift and depression.   As the result of prolonged uplift peneplained lowlands have been raised to form upland plateaus.   A repetition of this movement in turn converted these into highland plateaus (Fig. 103).

With each renewed increase in height, the rivers and streams were also uplifted and thus became rejuvenated.   That is to say, they began to flow more rapidly, and to erode their beds, with the result that narrow, steep-sided valleys were incised along the floors of the broad, shallow valleys of the plateau (Fig. 106).   Where the rivers meandered the resulting valleys meandered also (Fig. 107). Between these new valleys extensive portions of the original plateau
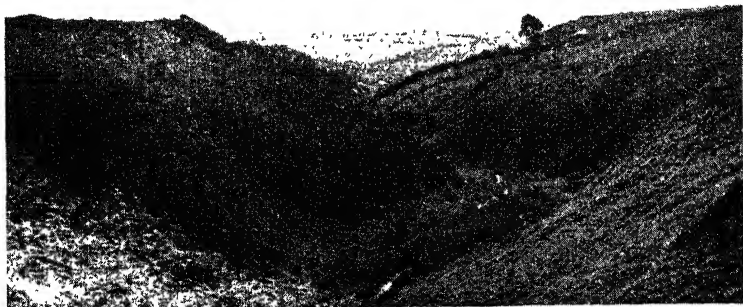
FIG. 108.   THE SOLVA VALLEY, PEMBROKESHIRE

The uplift of the peneplained surface, which gave rise to the platform seen in Fig. 107, has brought about the rejuvenation of the river Solva, and has resulted in renewed erosion along its course and the formation of this narrow steep-sided valley (cf. Fig. 25 A).

Photo H. H. Swinnerton

FIG. 109.   THE SOLVA ESTUARY, PEMBROKESHIRE

Since the uplift of the platform and the excavation of the Solva Valley the area has been slightly lowered, with the result that the sea has flowed into and submerged the lowest reaches of the valley (cf. also Fig. 178).

Photo H. H. Swinnerton

FIG. 110. THE EBRO VALLEY, NORTH OF BURGOS, SPAIN

This valley is deeply incised into the Spanish Plateau, which can be seen in profile on the skyline, and has an altitude of more than 3000 feet.

Photo H. H. Swinnerton

FIG. 111. THE SPANISH PLATEAU, NORTH OF BURGOS, SPAIN

This peneplained surface is traversed by the deeply incised valley of the Ebro,.the steep margins of which are seen in the middle distance and on the distant skyline.

Photo H. H. Swinnerton

still remained. A plateau showing such features as these is said to be in an early stage of dissection, as, for example, in the South Wales and the Cornwall-Devon peninsula (Figs. 105 to 108, 110 to 111).

When the lower reaches of the rivers have once more eroded their beds down almost to sea-level or **base level** (Figs. *cf.* 29, 30) further deepening of the valley gradually ceases, but widening goes on unchecked until a stage may be attained in which the remnants of the plateau are to be found only in the flat tops of the mountains or in the uniform height of their peaks (*cf.* Fig. 25). This stage is exemplified in parts of the Highlands of Scotland, the Lake District, and North Wales, and in comparable areas. It is presumed that if no further uplift takes place even these mountains and peaks will in time be reduced to gently rising hills, and that complete peneplanation will be accomplished once more. This sequence of events, commencing with uplift, followed by dissection, denudation, and ending in peneplain formation, may be described as a **physiographic cycle**. This is, of course, a much shorter and smaller-scaled sequence of events than a geological cycle, within which it is no more than a passing incident.

Meanwhile, movements of depression may sometimes take place, leading to more or less extensive submergence of the newly formed peneplains. These then become areas of deposition wherein new unconformities may be established.

Casting our gaze backward across the ages towards the far-distant and dim vistas of geological time, we seem to see that it is divided by a succession of majestic cycles of events, the records of which become more tattered the farther back we peer.

THE NATURAL HISTORY OF A PRIMEVAL SEA

THE joys of a holiday by the seaside include catching shrimps, hunting for crabs, looking for sea-anemones, shells, and starfish. If our luck is out and we catch none of these alive we are sure to find some remains of creatures that have been dead long enough for their soft flesh to decay and disappear, leaving their hard parts—shells and skeletons—washed clean and lying about on the sand. Sometimes these are only broken fragments of which we say, " This is the claw of a crab, that a bit of a starfish." After a day or two of rough stormy weather tangled heaps of seaweed and sea-mosses, torn by the waves from the floor of the sea, lie piled upon the beach. Searching among this, we come upon other creatures we may never have found before—sea-urchins, heart-urchins, or it may be a sea-mouse, a curious rusk-shaped worm, covered with hairs shining with all the colours of a rainbow. These finds give us peeps at the amazing variety of animals that we should see living in the sea if we could go swimming, with our eyes open, along the bottom.

A similar pleasure is felt by the geologist who goes hunting for fossils in the rocks. Every one that he finds is a relic, more or less complete, of some creature that lived in the seas of past ages of the earth's history. As the result of patient hunting and collecting by many workers for more than a century, many clues and much evidence have been accumulated for painting a picture of the natural history of those seas.

As already seen, the rocks formed in pre-Cambrian times have been largely worn away and destroyed. Those that are left have been in existence such a long time, and have passed through such varied experiences, that they have been completely changed in character. It is not surprising, therefore, that most of the fossils which they may have contained originally have been destroyed. Moreover, it seems not unlikely that the ability to make shells and skeletons came late in the history of animal life on the earth, so that few, if any, records of the earlier generations may be expected. Since our knowledge of the natural history of pre-Cambrian seas is as yet very scanty, we must pass on to look into the waters of that lower Palæozoic sea which covered so much of the British area

before the birth of the Caledonian mountain system. A glance at
the geological map will show where the rocks formed in those
waters are to be found to-day.

Among the most interesting fossils found in those rocks are the
trilobites (Fig. 112).   A first glance at a trilobite suggests a
resemblance to a wood-louse in shape and in the division of the
body into a number of short segments.   It differs from this, how-
ever, in many respects, including the presence of two grooves
running nearly the whole length of the body, which thus appears
to be divided into three longitudinal divisions—a middle, or axial,
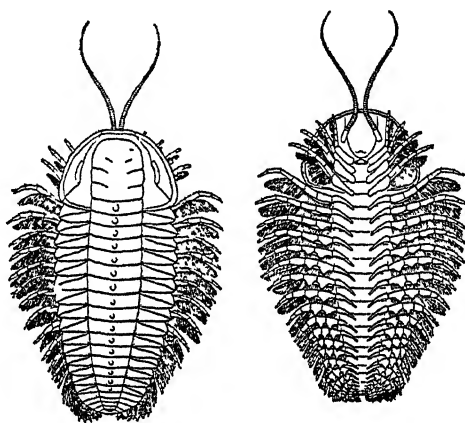
FIG. 112.   A TRILOBITE (TRIARTHRUS)
Upper and under views are shown here.
From Grabau's " A Text-book of Geology," Part II
(After Beecher)

portion and two side portions.   Hence the name ' trilobite.'   The
head, unlike the rest of the body, is not so clearly divided into
segments.   Its axial portion is called the **glabella** and its side portions
the cheeks.   Running from front to back across the cheeks is a
scratch-like groove, the **facial suture.**   Very often the fossil is
broken into pieces along this line, in the middle of which stands
the eye.   At the hind end of the body a number of the segments
are fused together into one piece, the **tail.**   Between the head and
the tail pieces lies the **thorax,** in which the segments are hinged on
to one another so that the animal could bend its body until the tail
lay along the underside of the head.

On rare occasions specimens have been found in which the
underside of the body could be seen.   These show that the trilobite

had as many legs as a centipede, there being one pair on each segment. Each leg has two branches—a lower, or inner, branch · divided into a number of sections like an insect's leg, and ending in two tiny hook-like claws, and an upper, or outer, branch looking like a feather with one vane, having its shaft divided into a multitude of very small divisions. While all the inner branches, working together, enabled the trilobite to walk on the sea-bottom, it was able, with its outer branches, to rise and swim with a gliding motion freely through the water. When alarmed it could flick its tail rapidly forward and so dart backward out of danger.

Remains of trilobites have been found even in the oldest layers of rock formed in lower Palæozoic times. This fact suggests that some of these creatures existed in late pre-Cambrian waters. From the opening of the Palæozoic onward they increased in numbers and variety. Though their normal length is an inch or two, individuals have been found that were as many as two feet long. While many lived normally on or close to the sea-bottom others adopted a more special mode of life, either tunnelling into or through the mud in search of food, or swimming freely, or merely floating in the waters of the open sea. In that ancient sea there were no crabs, lobsters, shrimps, and the like ; the place of these in Nature was occupied by the trilobites.

Towards the end of the lower Palæozoic period this race of animals began to decline, and another kind of arthropod rose to its heyday. This included the sea scorpions (Eurypterids), so called because in shape of body, number of legs, and in other respects they resembled scorpions (Fig. 113). Unlike these, however, they did not live on land but in water, and breathed by means of gills. Some of these sea animals were as much as five or six feet long and all of them were fierce, agile creatures that preyed upon trilobites and other small fry. Their bullying reign did not last long, for primitive sharks began to appear. These were the earliest back-boned animals, or **vertebrates,** of which fossil remains have been found.

All these creatures lived in the shallow water not far from the shore. In some areas, especially in the vicinity of the Welsh border country, the water was clear and sunlit. Here stone lilies, which are allied to starfish and sea-urchins, abounded. Sometimes coral polypes, which look like miniature sea-anemones, were common, and built up masses of coral that helped to form long reefs. The smaller types of polype made simple tubular skeletons which were

packed closely side by side, so that the whole coral looks like a
honey-comb.   The larger kinds strengthened their tubes with
vertical partitions, or septa.   In amongst the rather massive coral
colonies lived lamp shells, made of two valves hinged together one
above the other, and often beautifully decorated with folds, ridges,
and grooves.   All these, and many other interesting little creatures,
lived, died, and left their hard, shelly skeletons in and around the
reefs.   In stormy weather the waves pounded against the reefs,
breaking some of the corals and other remains to fragments, or

FIG. 113. ANIMAL LIFE IN THE SILURIAN SEA
Large sea-scorpions (Eurypterids) and small trilobites swimming about among stone-lilies.
On the floor are corals, lamp shells, and trilobites.

grinding them to sand and mud, which gradually covered up and
buried the less-broken skeletons.   With the passage of time all this
became compacted into hard rock, one of the most famous examples
of which is now called the Wenlock Limestone (Fig. 114).
     Out in the deep waters of the open sea multitudes of **graptolites**
lived, floating about in populous colonies (Fig. 115).   The tiny
creatures which lived in them were like miniature coral polypes.
In this case, however, each individual was connected with its
neighbour by means of a fleshy tube, and the two were enclosed in
a horny covering.   The chambers which surrounded each polype
were built, in ribbon-development style, in long rows alongside a

ad which hung down from a float.   When these colonies
sh decayed, but the horny remains sank through the
waters and became buried in the fine black mud at the
-day they are found preserved in black shale, some-
it numbers.   Quite often they look strikingly like lead-
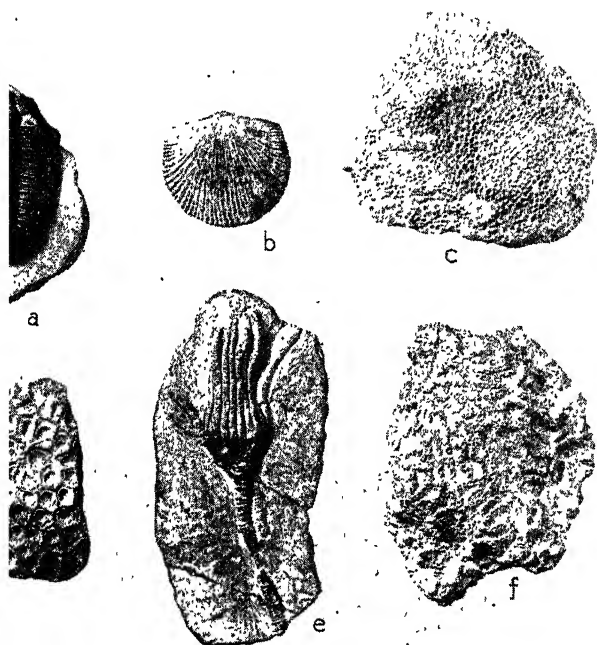
R PALÆOZOIC FOSSILS FOUND IN THE WENLOCK LIMESTONE
(SILURIAN)

ymene) ;   (b) Brachiopod, or lamp shell (Schuchertella) ;   (c) Honey-comb Coral
Septate coral Acervularia) ;   (e) Stone-lily (Desmidocrinus) ;   (f) Chain Coral
(Halysites).

By courtesy of W. Sutcliffe, Esq.

s upon the surface of the shaly slab.   That is perhaps
why early workers called them **grapholiths.**
ptolites appeared first upon the scene a long time after
of the Lower Palæozoic era.   They increased rapidly
and variety ; then, like the trilobites, they too began to
they died out at a much more rapid rate, and so disap-
oletely before the close of the era (Fig. 116).
sounds very peaceful.   Nevertheless, at about the time
ilobites and graptolites were approaching the high light

of their history great submarine volcanoes burst forth into activity in the areas of North Wales and the Lake District. Volcanic dust in large quantities was added to the normal marine muds, and
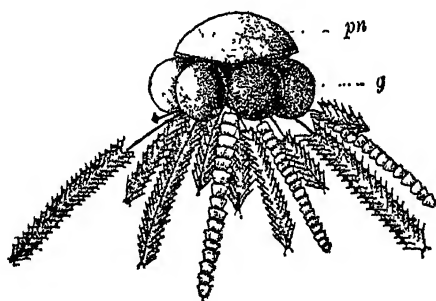
FIG. 115. A GRAPTOLITE COLONY (DIPLOGRAPTUS) RESTORED
The parts marked are *pn*, bladder-like float; *g*, reproductive sac.
From Grabau's " A Text-book of Geology," Part II
(After Ruedemann)

time after time lava poured forth and spread in extensive sheets upon the sea-floor. In the Lake District these volcanic muds and
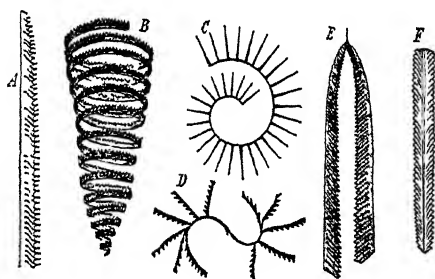
FIG. 116.   TYPES OF GRAPTOLITES
These are as follows : (*a*) Monograptus with one row of polype chambers or hydrothecæ ; (*b*) a spirally coiled Monograptus; (*c*) Rastrites, which has very long hydrothecæ standing out at right angles to the main axis ; (*d*) Cœnograptus, a form with a number of branches regularly arranged on an S-shaped axis ; (*e*) Didymograptus, with two branches each with one series of hydrothecæ ; (*f*) Diplograptus, with two rows of hydrothecæ placed back to back.
From Grabau's " A Text-book of Geology," Part II

lavas mounted up to a total thickness of 10,000 feet. To-day the rocks formed from them have been carved into scenery of surpassing grandeur.

AN EVER-CHANGING SCENE

THE uprising of the Caledonian mountains brought about a complete change in the geography of the British area. As individual ranges rose up from the floor of the Lower Palæozoic sea they formed promontories half enclosing long estuaries in the south, and isolated portions of the sea in the north (*cf.* Fig. 101).

In the south, over the region ranging from Cornwall and Devon to Belgium, the sea persisted, and additional deposits accumulated on its floor. These in due time formed considerable thicknesses of sandstone and shale. For a brief section of this period an archipelago of volcanoes appeared in the sea between the districts of Plymouth and Torquay. The ashes and lavas that were poured forth built up volcanic islands, around which they became interbedded with muddy sediments. On the flanks of these islands coral reefs grew, having the usual population of lamp shells and other creatures, including the now very rare race of trilobites. The period during which this was going on is called the **Devonian**. The limestones formed from the reef deposits, together with the volcanic ashes and the normal sandstone and shales, are spoken of as Devonian rocks, and are characterized by the fact that they were formed under marine conditions.

Meanwhile the fragments of sea, isolated in some of the hollows between the ranges of newly formed mountains, gradually changed into fresh-water lakes, and eventually were largely, if not completely, filled up with sediments. The trilobites, corals, stone-lilies, and lamp shells died out, but a few creatures became adapted to, or at least survived, the advent of quite new conditions. Among these were the sea scorpions. Strange new types of fishes appeared, many of which had their heads and the front parts of their bodies enclosed in a stout armour of bone. Half of these belonged to a primitive vertebrate race, represented to-day by the lamprey, which had not yet acquired jaws and paired limbs. With them there lived fishes of a more advanced and, to us, more normal type, in that their mouths were armed with jaws and their bodies furnished with paired fins. These fins, unlike those of fishes with which we are so familiar to-day, had a stout, fleshy support running down

the centre   Along the edges of this ran a fringe of delicate rays,
supporting a thin film of skin (Fig 117)   They are spoken of as
the fringe-finned fishes, or **Crossopterygii**. It is well worth while
learning the name, even if it is a long one, for these fishes were the
forerunners of the land animals, and were therefore our own very
remote ancestors

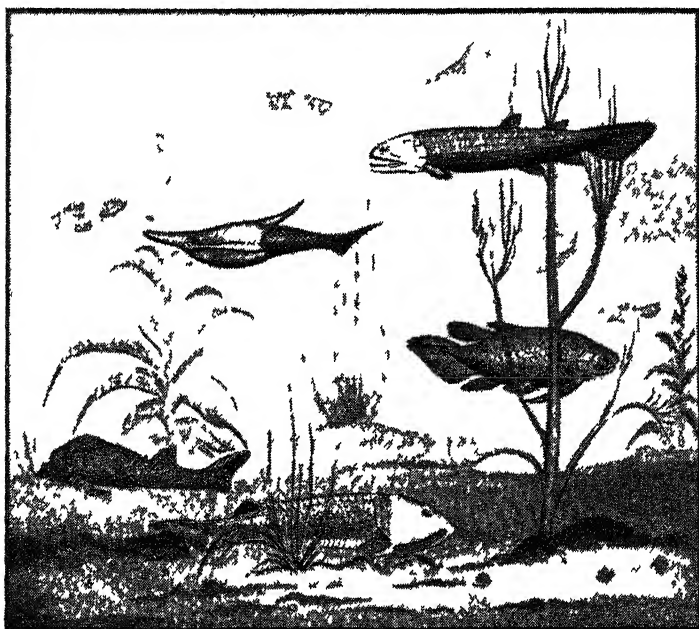The waste formed by the destruction of the mountains filled

FIG 117   FRESH-WATER FISHES OF THE OLD RED SANDSTONE
The three on the left are primitive fishes without paired fins or jaws   The two on the right are
more advanced forms, with paired fins and strong jaws

up the lake basins and the estuaries, and was spread out over much
of the lowlands. The predominant colour of these deposits is red.
At the present day soils and deposits of a similar colour are being
formed in those parts of the world where the climate is characterized
by a dry and a wet season. During the dry season the air penetrates
the ground and completely oxidizes the iron dust. It is not un-
likely that during Devonian times the climate of the British area,
and other portions of the continent of which it formed a part, was
of the same type. These red deposits have now become the rocks
known as the **Old Red Sandstone.**   They were formed at the

same time as the Devonian rocks, but unlike these they were deposited in the hollows and on the low-lying portions of a land

Atlantic Continent

Muddy Seas

Coral Seas

Muddy Seas

St George's Land

Coral Seas

Muddy Seas

--- Deltaic area subject to marine inundation
.. Muddy seas
Clear sunlit coral seas
- - Forests
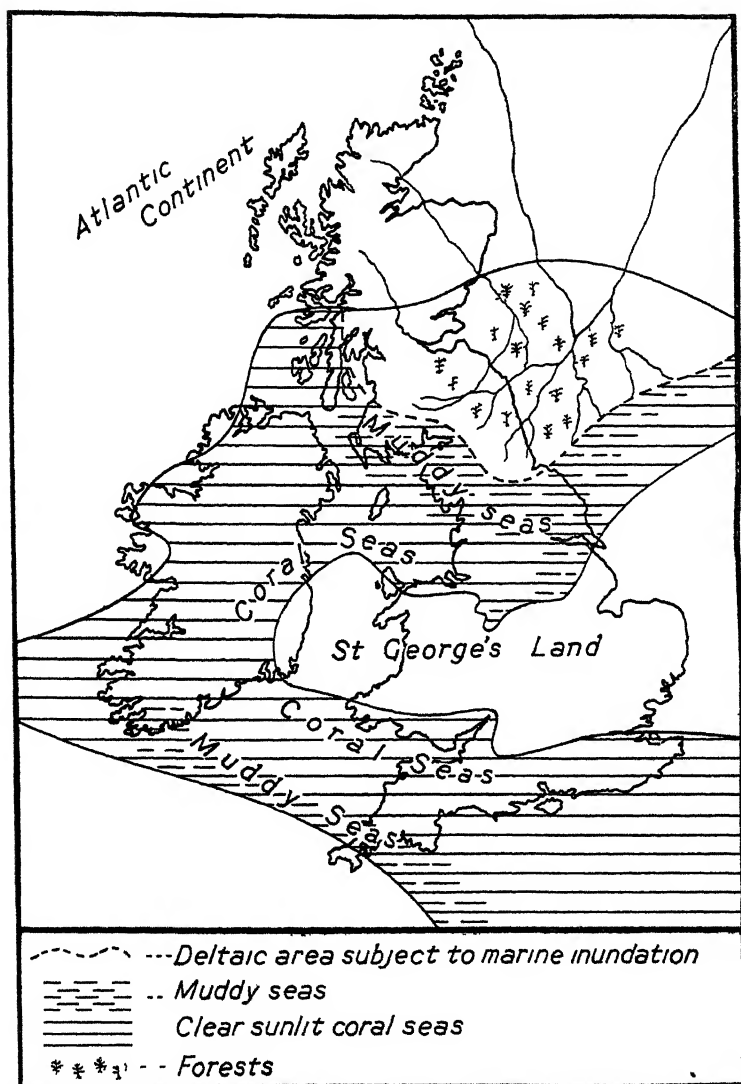
FIG 118   A MAP OF THE BRITISH AREA IN EARLY CARBONIFEROUS TIMES

surface. Deposits formed under such conditions are usually referred to as terrestrial deposits.

At the end of the Devonian and Old Red Sandstone period a gradual sinking of the land took place, accompanied by a slow encroachment of the sea upon the lowlands. This continued until much of the British area was covered by a sea, bounded on the north by the Highlands of Scotland and surrounding an island, often called St George's Land, which extended from the South-east of Ireland across Central Wales to the Midlands and East
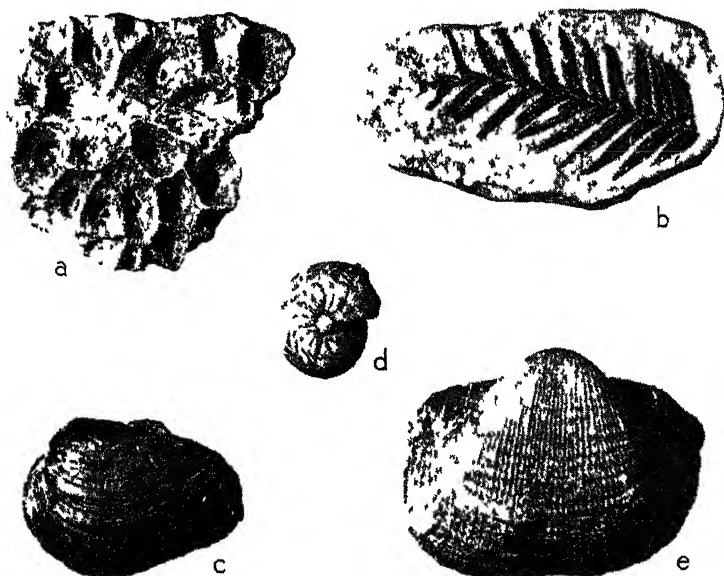
FIG. 119   CARBONIFEROUS FOSSILS

These are (*a*) Coral (Lonsdaleia) , (*b*) Fern leaf (Alethopteris) , (*c*) Carbonicola , (*d*) Goniatites , (*e*) Brachiopod (Productus).   Three are found in limestone—(*a*), (*d*), and (*e*), while (*b*) and (*c*) come from coal-measures

By courtesy of W. Sutcliffe, Esq.

Anglia (Fig. 118). The rivers on this island were too small to bring an appreciable body of sediments down to the sea. Around it, therefore, the waters were clear and sunlit and abounded with corals, stone-lilies, and giant lamp shells growing on the bottom (Fig. 119). Above these swam goniatites and orthoceras with chambered shells like that of the modern nautilus and rare trilobites, the last representatives of a race that was now rapidly approaching complete extinction. The remains of all these, often fragmentary and pulverized, accumulated to form limestones as much as 2000

feet thick. The Derbyshire limestone already mentioned several times was formed then.

Far away beyond the northern shoreline of this sea stretched a great continent occupying the site of the present North Atlantic Ocean. Great rivers, flowing southward across this, poured their
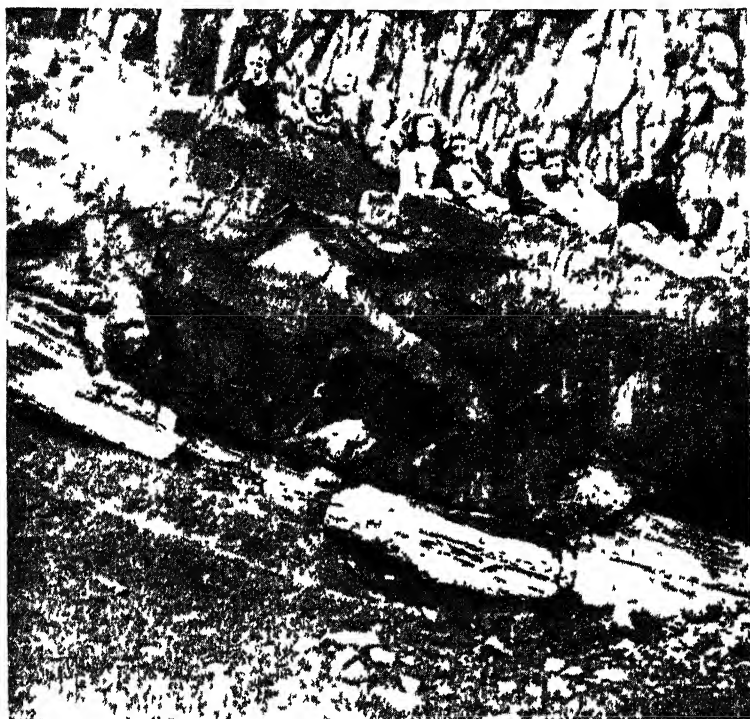
FIG 120. SALISBURY CRAG, FDINBURGH

The major part of the picture shows a dark-coloured rock, part of the base of a great sheet or sill of igneous rock (see p. 83) In its original hot liquid state this was injected into and between layers of Lower Carboniferous sandstone, a portion of which may be seen just above the grassy slope The junction line of the two rocks is irregular because the hot liquid dissolved much of the sandstone.   On the right a piece of sandstone is seen broken off, but not dissolved by the liquid

Photo H H Swinnerton

waters, laden with sediments, into this sea and built up extensive deltaic flats (Fig. 122). Occasionally the conditions on these were favourable to the growth of vegetation and even forests for centuries, or at times millenniums. The debris of leaves, twigs, and trunks accumulated to depths of as much as thirty, forty, or even fifty feet. Eventually slow sinking of the ground reintroduced conditions unfavourable to plant life. The debris that had accumulated became

buried under thick deposits of sand and mud, and
coal. Occasionally a brief period of rapid sinking re
complete inundation of the whole extent of deltaic
water, and the deposition upon them of layers of marin
including limestone.

Owing possibly to a rise in altitude of the contin
consequent rejuvenation of the drainage and weather
the rivers brought increased quantities of sediment to
the deltas were extended as far southward as St Ge
eventually covering most of its lower ground. The ea
sediments included much coarse, gritty sand, which
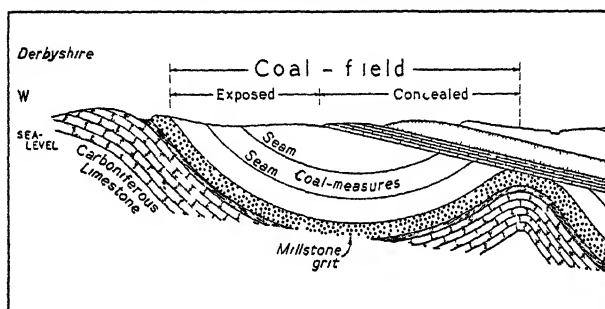
Fig. 121. A GEOLOGICAL SECTION FROM DERBYSHIRE TO LIN
THE MIDDLE OF FIG. 9

This shows how the Carboniferous rocks of this part of England were folded
the Hercynian mountain-building movements. As the upfolds arose the coal-r
from off their crests, but were left almost intact in the troughs of the downfo
and later rocks were laid down unconformably over the whole of this eroded surfa
rocks. These later rocks have since been partially removed, so that the coal
half concealed and half revealed.

consolidated to form Millstone grit. Subsequently t
mainly of mud with some sand which accumulated t
varying from 4000 to 7000 feet. The process of de
punctuated at intervals by the establishment of condi
able to plant life and the growth of forests, the debri
eventually became converted into coal-seams (cf. F
126). At such times these primeval fenlands were
innumerable sluggish streams and dotted with pools
fresh water in which multitudes of **Carbonicola** and c
bivalve shells swarmed. Marine inundations occurre
are represented now by beds of black shale known
bands, because they contain marine fossils. The
from all these deposits are called coal-measures, of
about 1 per cent. consists actually of coal.

Atlantic
Continent

St George's
Land

☀☀ ☀☀	Flat marsh and fenland, subject to flooding by rivers and occasional inundation by sea
🌲🌲	Forests on slightly higher ground
░░░	Bog
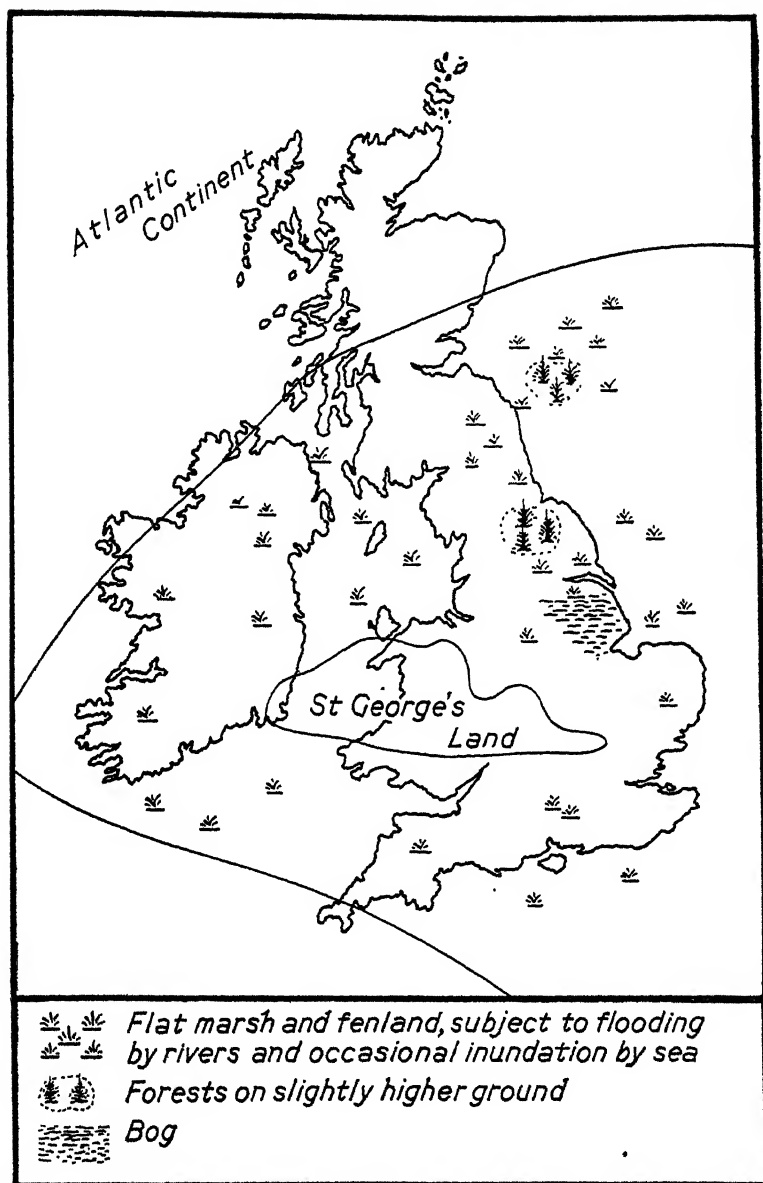
Fig. 122. MAP OF BRITISH AREA IN LATE CARBONIFEROUS TIMES
The low ground, including boggy patches, is drained by sluggish streams.

The presence of seams of coal in these rocks formed from the close of the Devonian period onward has earned for them the name of **carboniferous rocks,** and for the time of their formation the **carboniferous period.** In early, or Lower, Carboniferous times the conditions were prevailingly marine, but during Upper Carboniferous times they were predominantly estuarine and freshwater (Figs. 121, 122).

These ages of relative stagnation were brought to an end by the onset of the Hercynian mountain-building movements, which were accompanied by a change to a dry type of climate (*cf.* Fig. 133). The oncoming of this change is reflected in the red colour of the topmost portions of the coal-measures from the Midlands northward, and in the practical absence of coal-seams.

CHAPTER XXIV

THE EARLIEST FORESTS

WHEN out for a walk in the country you must often have noticed on tree-trunks and bare stone walls a green dusty covering, which can be scraped off with a pocket-knife. Examined under the microscope, this is seen to consist of multitudes of tiny, round plants belonging to a very lowly group known as the algæ. On similar, but rather drier, situations you have, no doubt, also seen
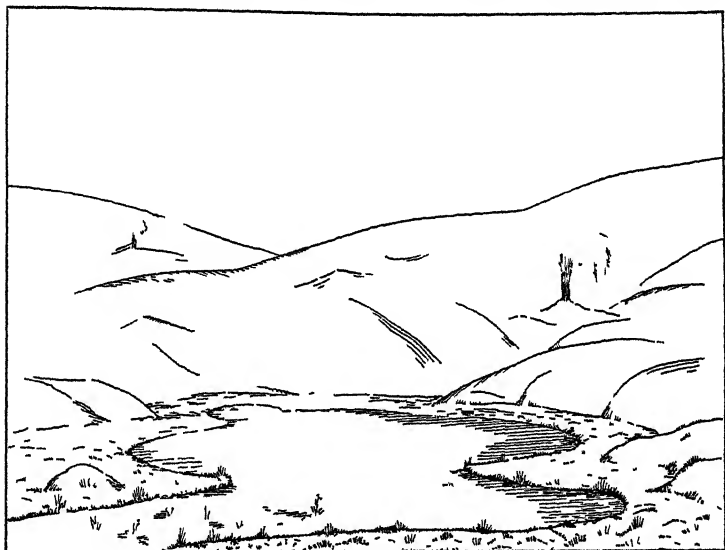
FIG 123. A HYPOTHETICAL RESTORATION OF A SCENE IN ABERDEENSHIRE
DURING MIDDLE OLD RED SANDSTONE TIMES

circular patches, grey or yellow in colour, of another interesting type of plant called the **lichens**. It is not difficult to believe that such primitive kinds of plants also grew on the bare rocky surfaces of the pre-Cambrian landscapes. There is as yet, however, no fossil evidence to prove that this was so.

In some of the older Palæozoic rocks fossils have been found which, there is good reason to believe, are the fragmentary remains of plants. It is not, however, until we come to the Old Red Sandstone rocks that we find undoubted fossil plants. These consist

for the most part of fragments flattened by pressure and blackened
by processes of carbonization. The scraps of knowledge yielded
by these have been composed into a nearly complete, though
miniature, picture by the fortunate discovery of an interesting
flint-like material, called chert, near Rhynie, in Aberdeenshire
(Fig. 123). Here, in Middle Old Red Sandstone times, a fresh-
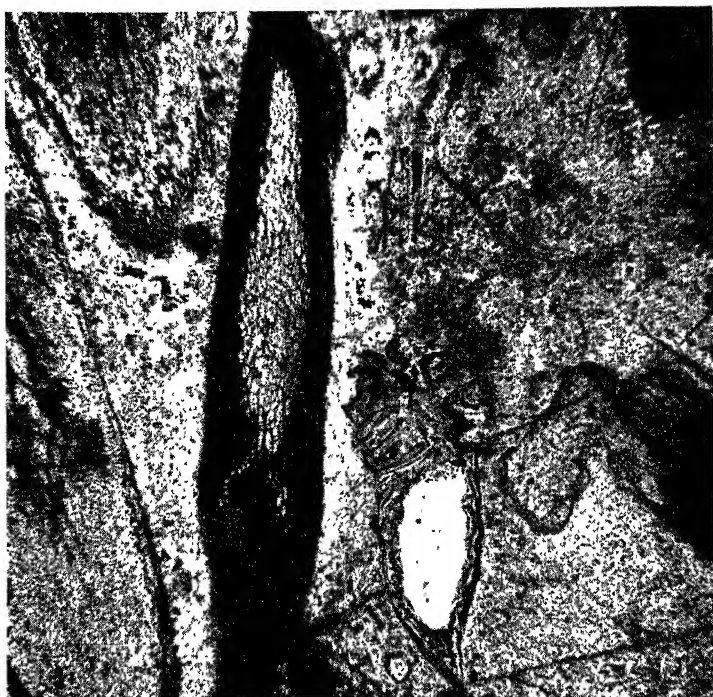
FIG. 124. THIN SLICE OF RHYNIE CHERT GREATLY MAGNIFIED
Left of the middle line is a long section of a plant showing delicate cellular structure. On
the right of the lower part of the line is a section through the body of an arachnid (Protacarus),
the earliest-known air-breathing animal.
By courtesy of W. Sutcliffe, Esq.

water lake existed, fringed here and there with marshes, beyond
which lay rising ground. In the shallow water and in the marsh
vegetation grew and died, gradually choking the lake margin, and
converting it into a peat bog. Normally the vegetable debris
would have rotted and perished utterly, but, owing to a peculiar
circumstance, this did not happen. The region around the lake
was beset with hot springs, whose waters found their way into the
bog, and impregnated the freshly forming peat with gelatinous

silica, which consolidated into chert and preserved the plant tissues from decomposition and from being crushed. Careful examination of this silicified peat reveals the most intimate details in the minute structure of these plants, and shows that, despite their moss-like appearance, they were more nearly related to the ferns (Fig. 124). Their main stems, which were either creeping or tuberous, were submerged in water or buried in the surface peat. Numerous branches rising upright only a few inches into the air carpeted the ground like a pixy forest. Fragments found in the rocks elsewhere give indications of the existence of other plants of stouter build and greater stature (Fig. 125).

In Upper Old Red Sandstone times plants of a different kind, and occasionally of tree-like proportions, appeared. These were the immediate forerunners of races which attained the climax of their development in Carboniferous times, and covered the coal-measure flats and sand-banks with extensive forests (Fig. 126).

Chief among these forest-trees was **Lepidodendron** (scaly branch), which grew to a height of sixty or seventy feet (Fig. 127). Its trunk forked and reforked at its apex into a system of branches covered with narrow, almost needle-like leaves. Each leaf, at its base, spread out into a diamond-shaped shield, which remained to form a kind of bark when the leaves themselves fell off. These bases gave to the surface of the trunk and branches the appearance of a scaly covering.

Fig. 125. A RESTORATION OF A PLANT (PSILOPHYTON) WHICH IS CHARACTERISTIC OF THE EARLY OLD RED SANDSTONE
From Grabau's " A Text-book of Geology," Part II
(After Dawson)

The delicate, twig-like ends of the branches hung down, and often carried at their tips a long, oval cone containing many small capsules filled with spores, often as fine as pollen dust, but sometimes as coarse as grit grains. When the spores were ripe they were shaken out of the capsules by the wind, carried in clouds over the forests, and dropped in large quantities

on the ground or the lakes where coal-forming peat was accumu-
lating. At its base the trunk of Lepidodendron divided into forking
branches which pushed their way into the ground and gave off
numerous simple short roots.

Other trees that were akin to Lepidodendron also shared in the
making of these forests. Among them was **Sigillaria,** in which
the skin of the trunk and branches was marked with vertical ridges
separating wide grooves out of which the leaves grew.

FIG. 126. A RESTORATION OF A COAL-MEASURE LANDSCAPE
Along the swampy borders of the sluggish stream giant horse-tails (Calamites) are
growing   On the slightly rising ground are branching lepidodendrons and unbranched
sigillarias. Over the water there skims a giant dragon-fly. In the foreground, on the
land, are two clumsy amphibia (Stegocephalia), and in the water a primitive reptile
(Limnoscelis).
From Grabau's " A Text-book of Geology," Part II
(After Williston)

Under the shadow of these larger forest-trees grew smaller ones
only ten to fifteen feet high. Most abundant was **Calamites,** a
giant relative of the horse-tails, or little ' Christmas trees ' which
may be seen growing in profusion in waste places to-day. The
main stem was divided into long sections devoid of leaves and
marked with delicate, vertical fluting. These sections were
separated by narrow grooves out of which leaves and branches grew.

Between the trees grew smaller plants, whose leaves bore a
striking resemblance to those of modern ferns. Many of these
plants, however, produced seeds, not spores—a difference of great

interest and vital importance. If spores fall on dry ground they merely die, but if they fall on wet ground they open. The large spores produce an apparatus that contains egg-cells. The small spores, on the other hand, release minute sperms which swim through the water and ultimately enter and fertilize the egg-cells, thereby rendering them capable of germinating and growing into new plants. Because this very essential incident in the life cycle of the plant can only take place in water these spore-bearers are unable to live and reproduce on really dry land, and are therefore
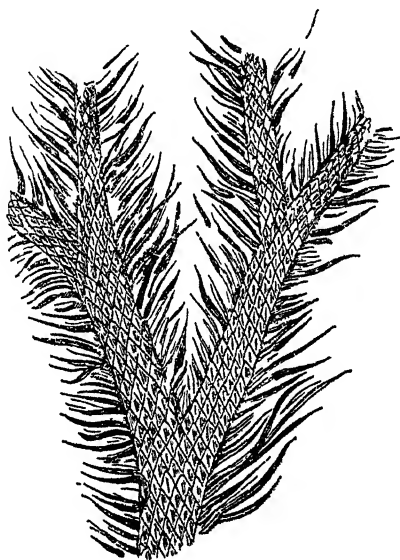
FIG. 127. A TWIG OF LEPIDODENDRON SHOWING LEAVES AND
SCALE-LIKE MARKINGS
From Grabau's " A Text-book of Geology," Part II

confined to moist or wet situations. Such was the case with Lepidodendron, Sigillaria, and Calamites.

In many of the small plants, however, the large spore and its capsule remained attached to the leaves and became enveloped in an apparatus designed for holding moisture. Any small spore, blown by the wind, might settle in this. There it opened and released sperms which found their way to the egg-cell and fertilized it. This then began to grow into a tiny seedling while as yet the whole apparatus was attached to the parent plant. The seed—for that is what we have been describing—eventually fell, the seedling became rooted in the ground and grew to form a new plant. Thus

the necessity for living in wet places was overcome, and seed-bearing plants capable of living on dry land had now come into being. Though these plants looked very much like ferns, they were not ferns, for they no longer reproduced their kind by spore but by seeds (Fig. 128).

At the present day there are two main kinds of seed-bearing plants. Some carry their seeds in pods, like the pea, or in capsules, like the poppy. Such are all classed together as the **Angiosperms.** Though they include all the flowering plants and to-day dominate the landscape, they were, as yet, unrepresented in Carboniferous times. Other seed-bearing plants have no such cases for their seeds, but carry them naked and exposed to the air. These are known as the **Gymnosperms** and include the pine-tree, yew, and cedar. Primitive fore-runners of these have been found among those ancient dwellers in the coal-measure forests.

Those landscapes of Old Red Sandstone and Carboniferous times were, then, devoid of flowers and grasses. The drier places were occupied sparsely by small plants having long, sword-shaped or fern-like leaves. In moist and wet situations these same plants provided a luxuriant undergrowth to the forests of Lepidodendron, Sigillaria, and Calamites.

FIG. 128. LEAF OF A FOSSIL SEED-BEAR-ING FERN NEUROP-TERIS FROM THE COAL-MEASURES (*a*) Part of a frond, (*b*) leaflet enlarged to show the forked veins.

From Grabau's " A Text-book of Geology," Part II

Year after year leaves and spores, twigs and branches fell to the ground and, during storms, aged trees crashed down into their midst. This debris of the forest accumulated on the ground, or was carried by streams into shallow lakes where it helped to form peaty deposits of considerable depth. By processes as yet not fully understood, these were converted into coal. Looking at a piece of coal picked out of the scuttle, you will see that it is made of thin layers, some bright and shiny, others dull and hard but clean. Occasionally a dull surface appears to be dusty and makes a smear when it is stroked with the finger. Examined with a magnifying glass, this last looks like charred wood. Under a microscope it even shows the minute structure of wood. Thin slices of the clean, dull

coal show numerous spores in a black background, and the shiny coal has a brown colour and normally exhibits no traces of plant structure.

Here and there in the coal-measure landscape calcareous springs poured their water into the swamps and, by depositing lime in the peat, preserved this from turning into coal. Lumps of this fossilized peat are found in some mines, and are known as ' coal balls ' (Fig.

FIG. 129   A THIN SLICE OF FOSSIL PEAT (GREATLY MAGNIFIED)
PRESERVED IN COAL BALLS
By courtesy of W. Sutcliffe, Esq.

129). By examining thin slices made from these a great deal has been learned about the minute structure of the plants. Much knowledge of the shapes of leaves, markings on bark, methods of branching, and other larger features have been gained from fossils which may be often collected in quantity from the tip-heaps of collieries. There also the collector will find specimens of Carboni-cola and also the scales, bones, and teeth of fishes. Fossils from marine bands are, of course, not so easy to find.

L

CHAPTER XXV

THE FIRST LAND ANIMALS

THROUGHOUT Palæozoic times the seas and oceans must have covered three-quarters of the globe as they do to-day, and have provided a safe and unchanging home for vast multitudes of living creatures. Everywhere along the fringes of the sea and land, however, slow, continual changes of the kind already described for the British area went on. Mountain ranges, lowlands, islands, rose out of the sea, carrying with them isolated bodies of water, which eventually either disappeared or changed into fresh-water lakes. Of those creatures that were trapped in such unstable surroundings the majority died out, but a few kinds became adapted to living in fresh-water or even on dry land. Thus new realms were discovered which opened out endless possibilities for further adventure and development. By piecing together evidence yielded by fossils from rocks in various parts of the world, the broad outlines of the early history of land animals have been revealed.

Even in the earliest Palæozoic seas worms abounded, for numerous examples of their burrows in sand and mud have been preserved. Some of these worms must have found little difficulty in becoming adapted to live in moist soil on the land. No doubt the ordinary earthworm originated in some such way as this.

In order that creatures may live comfortably above the soil on the ground one main difficulty to be overcome, in passing from being surrounded by water to being exposed to the air, is to avoid becoming dried up by rapid loss of water through evaporation from the body. A few sea-snails, such as limpets and dog-whelks, survive exposure to the air for a few hours when the tide is out by clamping their shells closely against the rocks. The presence of land-snails in late Palæozoic rocks shows that some had already found in their shells a sufficient protection. But they cannot be regarded as very successful land animals. For winners in this part of life's race we must go to the Arthropods and Vertebrates.

The Arthropods started off with two great initial advantages. They already possessed an impervious shelly covering which could act as an efficient preventive against excessive loss of moisture. In addition they had legs which could replace the buoyant action of

162

the water as a means of supporting the weight of the body. With such a good start it is not surprising that in the form of insects and arachnids they produced the first really successful invaders of dry land. Which among their marine predecessors were their immediate ancestors still remains to be proved, for fossils that show the transitional stages are unknown. Trilobites and eurypterids may claim to be close relatives.

Fossil remains of forms resembling cockroaches and dragon-flies occur in the Carboniferous rocks, thus proving that insects had already invaded the air as well as the land. In the air there were as yet no rivals :

> No birds were flying overhead—
> There were no birds to fly.

It is not surprising, therefore, that some flying insects attained amazing sizes ; for example, some of them that glided to and fro—like dragon-flies—in the sunshine over the coal-measure swamps and marshes, had a stretch of wings of as much as two feet from tip to tip (Fig. 130).

The presence in the Rhynie chert of the remains of ' mites ' appears to give to these tiny arachnids the honour of being the earliest air-breathing animals (*cf.* Fig. 124). These were followed in Carboniferous times by considerable numbers and even varieties of arachnids, including among them the first of the scorpions—Eoscorpius (Fig. 131).

The other successful invaders of the land were the Vertebrates. Their initial progress was not so rapid as that of the Arthropods, for as fishes they had no legs, and their skins were moist and only partially shielded by scales. Nevertheless, in the end their adaptation to land conditions was on the whole more effective.

Among the fishes that lived in the fresh waters of the Old Red Sandstone continents, the Crossopterygii have so many features in common with the four-footed land-dwellers that they may be regarded as the most probable ancestors of these (*cf.* Fig. 117). Here again details of the actual transition stages are unknown. Thus, for example, the oldest of the known land forms already possessed typical legs divided into upper and lower portions and ending in feet with soles and toes, or digits. How the simple fleshy axis of the fish's fin changed into this more complicated leg is still an unsolved mystery. These legs were at first weak, flimsy structures, apparently quite incapable of carrying the weight of the body, but sufficiently strong, when assisted by wriggling movements

of the tail, to slither the body forward between the weeds that grew
on the slippery muds

The discovery of fossil tadpoles with feathery gills suggests
that, like newts and frogs, they laid their eggs and lived the early
part of their lives in water.   Throughout the greater part of
Carboniferous times these amphibious creatures were almost the
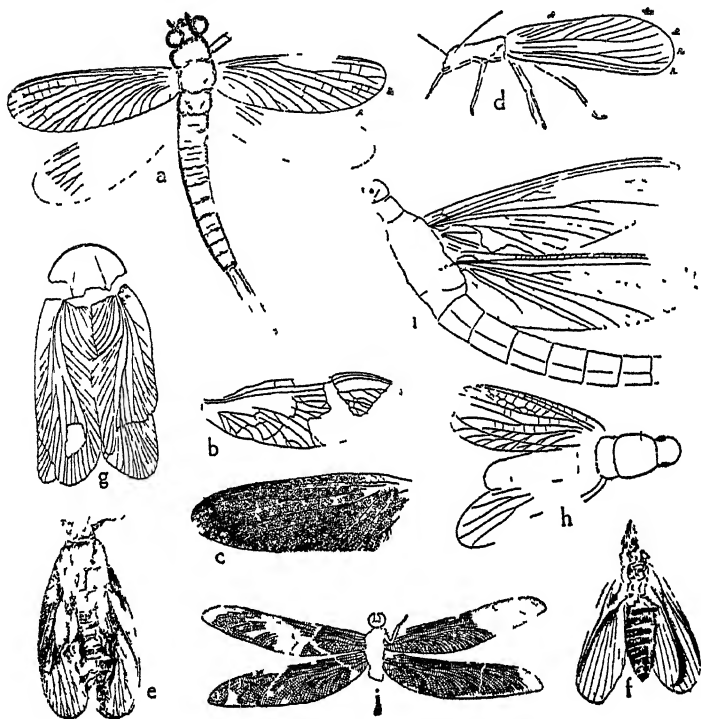
FIG 130   LATE PALÆOZOIC INSECTS

The great variety seen here shows how effectively insects had, in these early times, conquered
not only the land but also the air   (g) closely resembles the cockroach, and (j) the dragon-fly

From Grabau's " A Text-book of Geology," Part II

only four-footed animals in existence, for which reason that period
is often called the ' Age of Amphibia.'   Their normal shape was
that of the newt, having a small head, long body, and tail.   The
legs were bent downward at the elbows and knees, and had sufficient
strength to lift the body clear of the ground during the acts of
running or walking.   Their total length ranged from a few inches
to eight or more feet.   Deviations from this shape included some
that were greatly elongated like the snakes and, at the other extreme,

that were grotesquely short and stout (*cf* Fig 126). The
/as usually protected, as in the Crossopterygii, by a complete
t of bones similarly ornamented with a complex pattern of
and grooves. Because of this casing the larger amphibia are
Stegocephalia.

e much drier climate which set in at the close of Carboni-
times and lasted during the closing phases of the Palæozoic
ie opening of the Mesozoic eras did not, as might have
xpected, prove fatal to the amphibia. On the contrary, their
was such that they became adapted to and flourished in the
nditions.

ing side by side with the Carboniferous Stegocephalia were
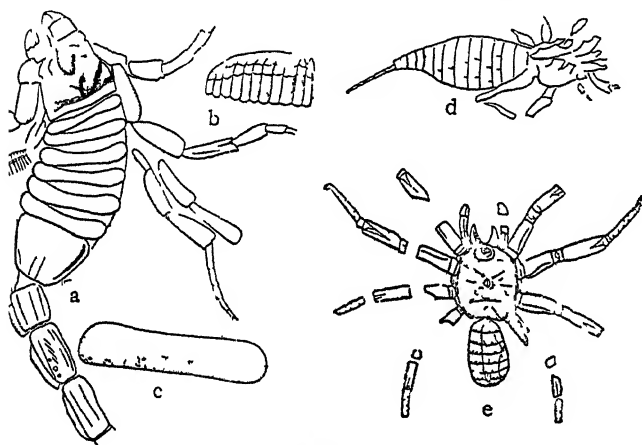
FIG 131   LATE PALÆOZOIC ARACHNIDS
serve the close resemblance of these ancient creatures to present-day scorpions
and spiders
From Grabau's " A Text-book of Geology," Part II

st representatives of the **Reptilia**, a race destined to reign as
of creation throughout Mesozoic times. Unlike the amphibia,
were not crippled by the necessity of laying their eggs and
ing their early life in water. Like the seed-bearing plants,
evolved a device which enabled them to circumvent that
antage and to spread far and wide over the landscape.

lough fossil eggs of early reptiles have not been found, it is
) assume that, like the eggs of existing reptiles, they were very
compared with those of frogs and other amphibia. As with
en's egg, the large yolk provided ample food for the nourish-
of the embryo while it developed to a stage at which it was

ready to breathe air and walk on land. Moreover, after the egg-cell had been fertilized within the parent's body this yolk was enclosed in a liquid cloak, familiarly called ' the white of egg ' and covered with shell. Thus the danger of drying up when exposed to the air
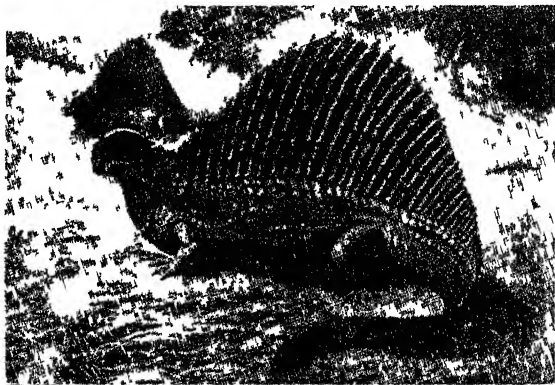
FIG 132   LATE PALÆOZOIC REPTILES
From Grabau's " A Text-book of Geology," Part II
(American Museum of Natural History)

was all but eliminated, and so the chief barrier to the invasion of the land was overcome. Thus equipped, the reptiles developed rapidly during the last section of the Palæozoic—the Permian— and rose to a position of ascendancy over the Amphibia (Fig. 132). The rest of their story will be told later.

CHAPTER XXVI

THE MIDDLE AGES

;reat Hercynian mountain-building movements which took
towards the end of the Palæozoic era marked the opening of
:r geological cycle. The British area once more became
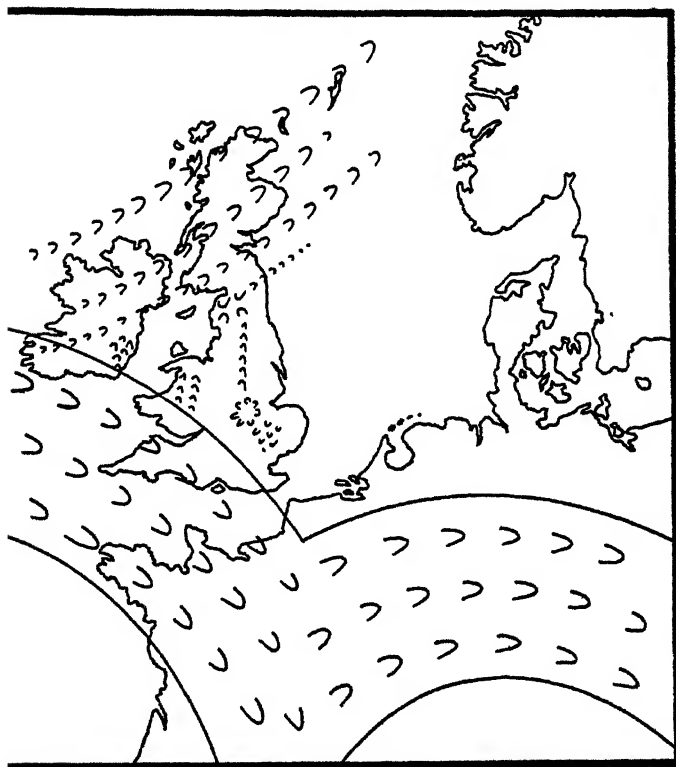
133. MAP OF BRITISH AREA AFTER THE HERCYNIAN MOUNTAIN-
BUILDING MOVEMENTS
nnants of the Caledonian System of mountains are indicated in the north, the newly
formed Hercynian system is shown in the south.

d into the North Atlantic and European continent. For a
an inland sea occupied the North of England and extended
ird into Europe. In this the last of the Palæozoic rocks, the
an, were laid down. Eventually this sea disappeared, and the

Mesozoic era began (Fig. 133). Though the climate was arid, rain still fell on the slopes of the newly formed mountain ranges bounding Britain on the south, and also upon the higher ground of the much reduced Caledonian highlands. That rainfall was sufficient to feed a few large rivers that discharged their waters, laden with rock-waste, into the lowland basins; and from season

FIG. 134. THE KEUPER, MAPPERLEY PARK, NOTTINGHAM
Here beds of light sandstone alternate with thin layers of dark red marls. The white patch at the foot of the post is the surface shown in Fig. 135.
Photo H. H. Swinnerton

to season replenished lakes which expanded and shrank in sympathy with wet and dry cycles of climate.

At first, rock destruction was rapid, and the deposits that accumulated in the basins were sandy and often pebbly, and amounted in some parts, as for example in Cheshire, to a depth of no less than 3000 feet. Thus the hollows in the landscape were partially filled up and converted into wide lowland plains. As the mountains and highlands became reduced in altitude the rate of destruction of rocks slowed down and the waste became finer-grained, ranging in texture from fine sand to mud. Meanwhile the climate underwent oscillations from drier to wetter conditions.

Some of these were merely seasonal, others ranged over many years. In association with these variations of climate, beds of sandstone and mud were laid down alternately (Fig. 134).

The streams and lakes were peopled by shoals of small fishes whose bodies were coated with ganoid scales, which were rhombic in shape and covered with shiny enamel. Alongside the rivers, and in marshy places, a sparse vegetation grew. This, together

FIG. 135. A RIPPLE-MARKED SURFACE, MAPPERLEY PARK, NOTTINGHAM

The cleaned surface of one layer of fine, silty sandstone is shown here. This was laid down in a shallow pool of water which was thrown into ripple by the wind. This caused the sand to become rippled also. After the water had sunk away, and before it had dried up, small reptiles ran hither and thither across it and left irregular tracks which are seen preserved here.

Photo H. H. Swinnerton

with the fish, supplied enough food for the support of a fauna of reptiles and amphibia. Fossil remains of these creatures are rare, but numerous traces of their existence have been found in the form of footprints (Fig. 135). The remains of small tropical animals, including scorpions, also occur.

The process of filling up the inland basins went so far that the lower hill country of St George's Land and the Pennines was buried, leaving only the higher ridges of the latter and the topmost peaks of Charnwood standing up above the surrounding plains. During wet seasons the streams coming down from the Hercynian and

Caledonian uplands covered broad areas of these plains with shallow sheets of muddy water. In the dry seasons these temporary bodies of water evaporated away, and the more permanent lakes shrank. These arid and semi-arid conditions lasted long enough for a depth of 600 feet of red marl to be built up out of the thin sheets of mud laid down in the ephemeral lakes, and for the complete burial of the Charnian peaks and Pennine ridges. Meanwhile the

FIG 136   SALT PSEUDOMORPHS FROM THE KEUPER, NEAR NOTTINGHAM
When the salt lakes of late Keuper times shrank or dried up in the dry season cubes of salt crystallized out in the mud   With the return of the wet season the rivers revived and filled the lakes once more   The fresh water dissolved the salt crystals and filled the cube-shaped spaces they occupied with mud   In due time these cubes of mud turned to stone, and their presence in the rocks is evidence of the existence of arid climates during Keuper times.
By courtesy of W Sutcliffe, Esq

mineral salts left behind by repeated evaporation accumulated in the waters of the lakes, until they became very saline and deposited beds of gypsum and salt (Fig. 136). To-day these provide material for a small but important mining industry.

The stretch of time during which all this happened is spoken of as the Triassic, and the rocks then formed are the Triassic rocks. During this time much of Southern Europe was occupied by sea in which typical marine deposits were formed and a rich fauna

lived. Some groups of animals, which had been prominent in Palæozoic seas—such as the trilobites—had now completely disappeared. Others, such as the brachiopods and stone-lilies, had become less numerous and varied. Others again had developed new characteristics and risen to greater prominence. Among the last were the descendants of the goniatites which now manifested
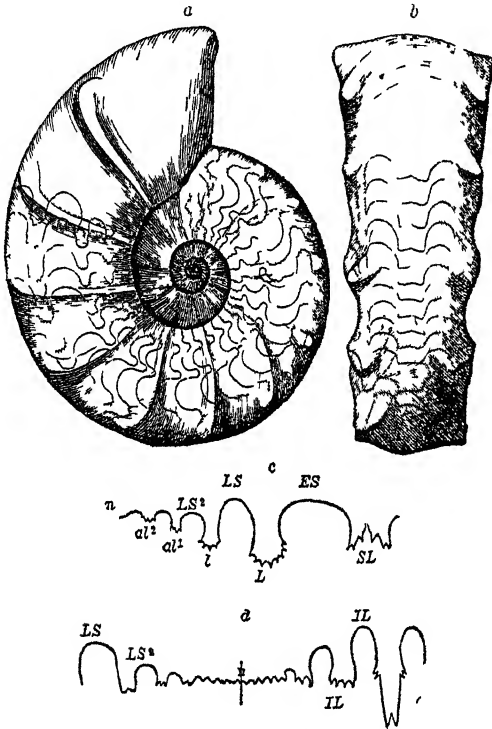
FIG. 137. A TRIASSIC AMMONITE (CERATITES)
The ornamental lines show the folded and frilled edges of the partitions which separate the chambers into which the cavity of the shell was originally divided
From Grabau's " A Text-book of Geology," Part II

every degree of complexity in the ornamentation of their shells and frilling of the margin of the septa which separated the chambers, into which they were divided, from one another. Shells having these characteristics are known as **Ammonites** (Fig. 137).

At the close of the Triassic period this sea began to encroach upon the lowlands of the continent. Flowing through the breaches in the Hercynian highlands, it entered the British area, inundating

the Triassic plains and forming a long inlet between the uplands of Wales and East Anglia in the south, and the highlands of the Lake District and Scotland in the north. Thus a new period, known as the **Jurassic**, was ushered in (Fig. 138). The deposits
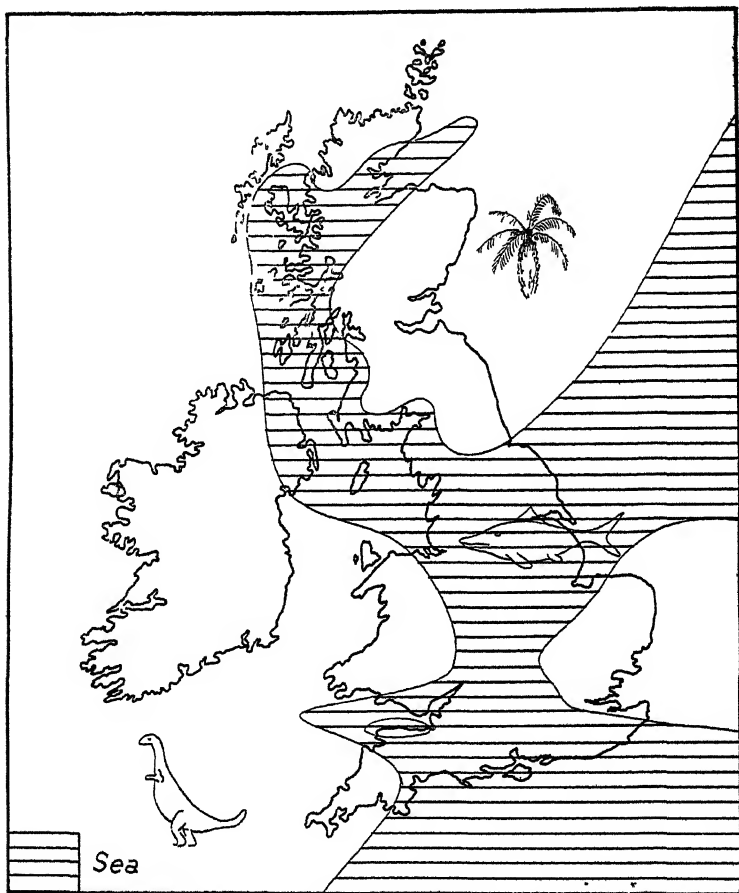
FIG. 138   MAP OF BRITISH AREA DURING JURASSIC TIMES
The shaded area is sea, the rest is land.   In the former is an ichthyosaurus.   On the latter is a dinosaur and a tree-fern.

laid down in the waters of this inlet were predominantly muddy, but for a while in the middle of the period the waters were clear and the sediments were limy, or calcareous. The muds formed those clays which underlie the important clay plains stretching across England from the Humber to the Dorset coast. The

calcareous deposits formed a series of limestones, often made up of round grains. These bear a superficial resemblance to the eggs in the roe of a fish, and the rock has accordingly received the name **oolitic limestone** (Fig. 139). This forms the prominent ranges of hills known as the Jurassic scarplands, of which the Cotswolds are a part. On either side of these hills lie the plains just mentioned. In both the clays and the oolite limestones important beds of iron-stone occur.

The Jurassic waters swarmed with many forms of animal life
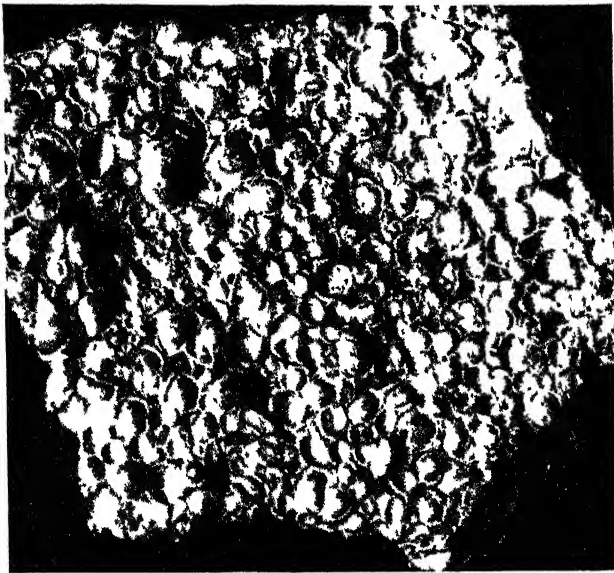
FIG. 139. A SPECIMEN OF THE VERY COARSE OOLITE KNOWN
AS PISOLITE
From Grabau's " A Text-book of Geology," Part

that varied from place to place according to conditions that pre-vailed locally. Among the bivalves were oysters which on several occasions gave rise to series of forms known collectively as **Gryphæa.** In them one valve became much thickened, and curved round like a claw. Locally stone-lilies were common and built up deposits from which crinoidal limestone was formed. Sea-urchins were a small but interesting part of the fauna (Fig. 140). Some of them, like **Cidaris** and **Hemicidaris**, retained the normal radial symmetry, but others struck out on a new line of evolution which resulted in a marked degree of bilateral symmetry. There were few types of

Brachiopods, but they occurred in large numbers. Some, like
Terebratula, were smooth, and had a shape similar to that of a
Roman lamp. Others, such as **Rhynchonella**, were prettily
ornamented. Perhaps the most important element in the fauna
were the Ammonites, with shells coiled in one plane and divided
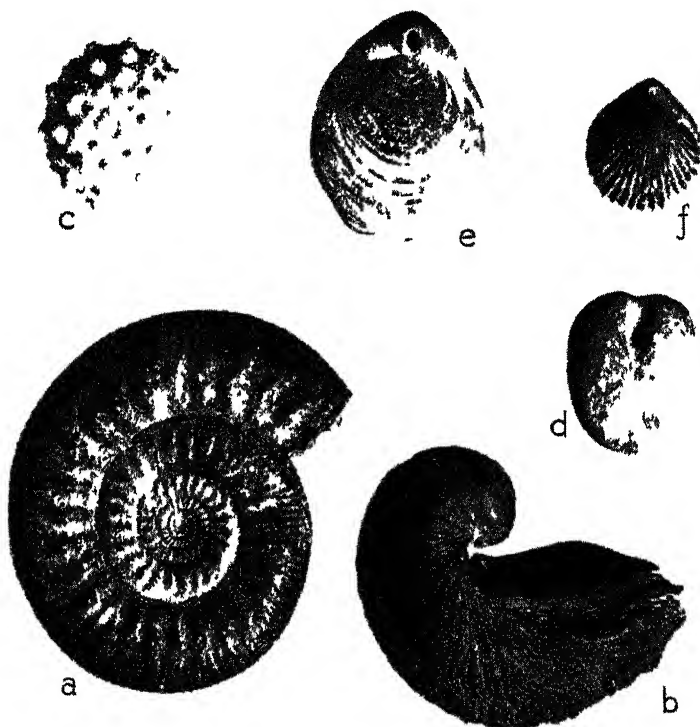
FIG 140. JURASSIC FOSSILS

(a) Ammonite , (b) Grvphæa ,(c) Hemicidaris, a radially symmetrical sea-urchin , (d) Nucleolites,
a bilaterally symmetrical sea-urchin , (e) Terebratula, a brachiopod, (f) Rhynchonella, a brachiopod.

By courtesy of W. Sutcliffe, Esq.

by thin partitions into numerous chambers. The fishes of this
period were clothed in thick rhomboid scales coated with shiny
enamel (Fig. 141).

That the lands bordering the Jurassic inlet were occupied by
plants and inhabited by reptiles is shown by fossil remains of both
that had been carried by rivers, down to the sea. The story of these
will be told in the next chapter.

While purely marine oolitic limestone was being formed in the south, conditions approximating to those of Coal Measure times prevailed in Yorkshire. There many fossil plants and occasional thin seams of coal may be found.

Towards the close of the Jurassic period the sea withdrew from the whole of the British area with the exception of that portion which now includes the Thames valley and the country lying south of this. Within the latter area conditions oscillated for a while between marine, fresh-water, and purely terrestrial, but eventually a large body of fresh water, popularly called the Wealden Lake, was established. The margins of this became fringed by a number of deltas, formed by rivers flowing from north and west.

It was at this time that a great marine transgression over the land began (Fig. 142). In the British area the sea made its first re-
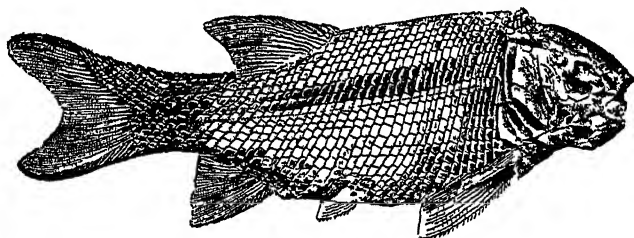
FIG. 141. A JURASSIC FISH (LEPIDOTUS)
This Jurassic fish has rhomboid scales, covered with shining enamel, which are known as ganoid scales.
From Grabau's " A Text-book of Geology," Part II

appearance over the regions of Yorkshire and Lincolnshire. A little later it also broke into the Wealden Lake. Gradually both bodies of water spread in all directions, and united with each other west of some uplands in the East Anglian region which are known as the London platform. At first the deposits laid down consisted mainly of mud and sand, often coloured by the presence of a green mineral called **glauconite**. The sea continued to spread until, in the opinion of some, it transgressed over and covered the whole of the British area with the exception of the highest lands of Wales and Scotland. At the same time the deposits came to consist of a fine whitish ooze or mud which has since consolidated and formed **chalk**, the thickness of which for extensive areas is more than 1000 feet (Fig. 143).

The waters of this chalk-forming, or **Cretaceous**, sea teemed with myriads of one-celled animals which built tiny shells about

the size of a pin's head. Their shapes were very varied, but the commonest was **Globigerina** (Fig. 144), so called because it was
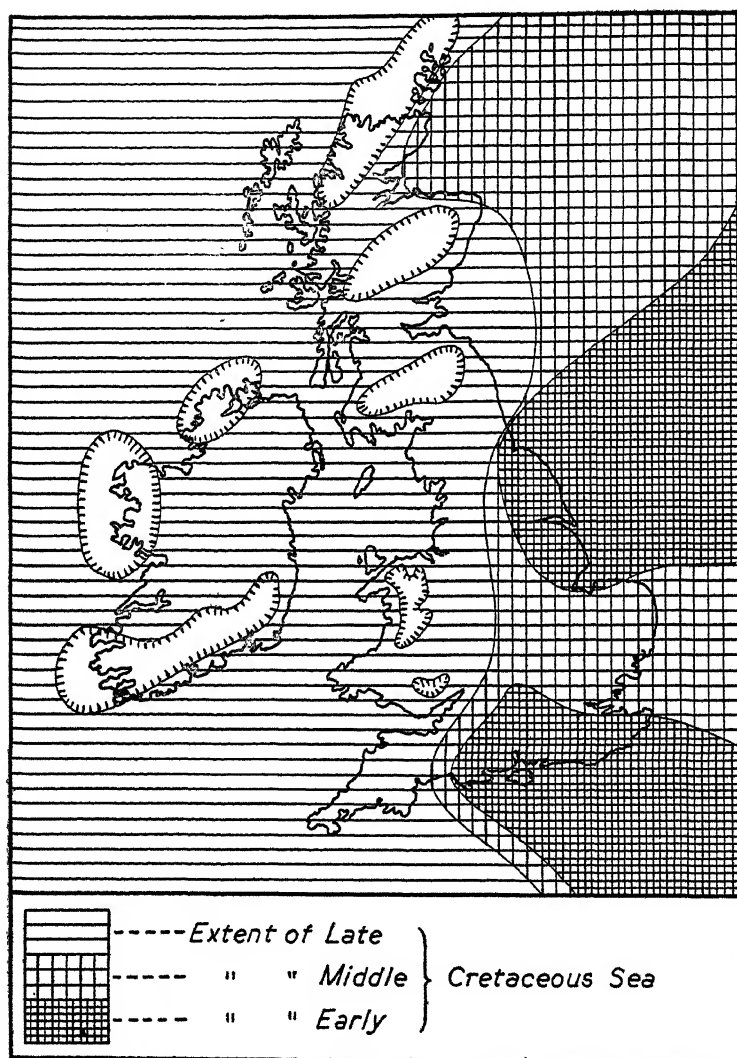
FIG. 142. MAP OF THE BRITISH AREA IN CRETACEOUS TIMES

built up of a series of globular chambers. The disintegrated remains of these formed a large proportion of the chalk deposits. Sea-urchins lived on the sea-floor, and included both radially and

FIG. 143. THE SEVEN SISTERS—THE CHALK CLIFFS OF SUSSEX
The crest of the cliff shows cross-sections of valleys and spurs of which large portions have been
destroyed by the action of the sea.
By courtesy of Hampton Luke, Esq.
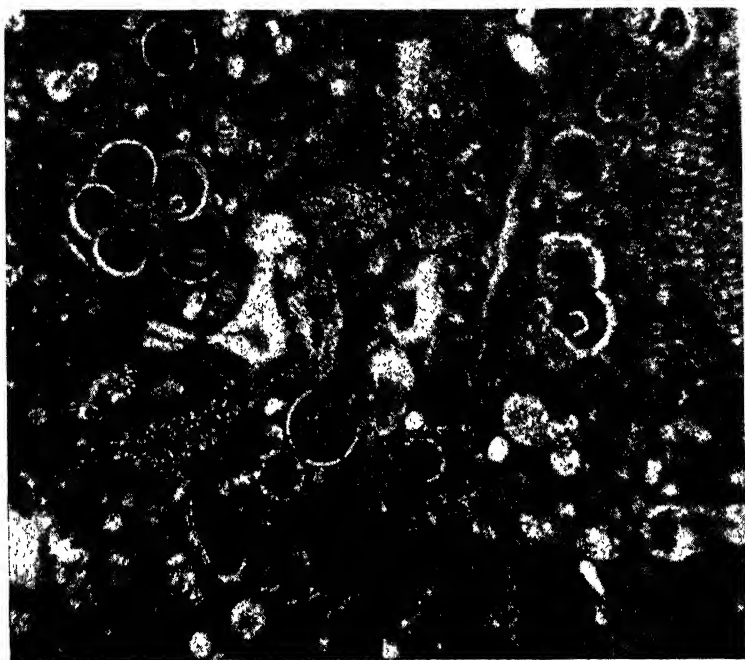
FIG. 144. A THIN SLICE OF CHALK, GREATLY MAGNIFIED
This shows many shells with single or with spirally arranged chambers belonging to globigerina.
The spaces between these are filled with pulverized and broken fragments of these and other shells.
By courtesy of W. Sutcliffe, Esq.

M

bilaterally symmetrical forms.   Among the latter was the handsome
heart-urchin, **Micraster** by name (Fig. 145).   Of other creatures
that existed then reference may be made to stone-lilies (Fig. 146)
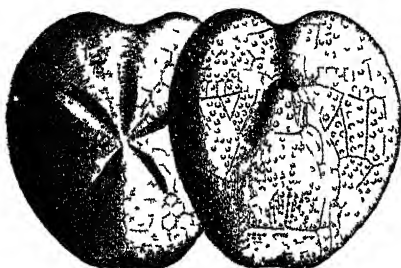
FIG. 145   A HEART-URCHIN (MICRASTER),
FROM THE CHALK
From Grabau's " A Text-book of Geology," Part II

FIG 146   A FLOAT-
ING STONE-LILY
(MARSUPITES)
FROM   THE
CHALK
*From Grabau's " A Text-
book of Geology," Part II*

that had abandoned their moorings and taken to a free, swimming
mode of life ; to fishes with bodies covered with thin overlapping
scales and supported by very bony skeletons ; to large aquatic
reptiles that found in these an ample supply of food.

MEDIEVAL REPTILES

BECAUSE mud and sand are continually accumulating on the sea-floor the remains of animals that live there are quickly imprisoned, and, consolidating with the deposits into rock, become fossils. It is not so with animals that live on the land, for when they die not only does their flesh decay but their bones, exposed to rain, frost, and sunshine, also rot away and disappear. Only when they happen to be caught and carried away by flood, trapped in a bog, or smothered by a fall of volcanic dust, may their remains be buried and preserved as fossils. For these reasons a clear picture of the Mesozoic land faunas and floras can be gained only by piecing together fragments of evidence from many parts of the world.

One animal in its lifetime may make many marks in muddy places. It is not surprising, therefore, that though fossil remains are few and far between, fossil footprints are not uncommon. Even in Britain quite a number of these have been found in the middle beds of the Triassic rocks. Usually it is not the actual print that is found, but a solid sandstone cast. The original print was made on half-dried mud or silt (Fig. 147). This was hardened by sunshine and then covered by sand brought by the wind or by flood-water. The sand filled the print and set hard as rock. When, in the course of quarrying or other operations, these layers are uncovered and exposed to the air the clay formed from the mud perishes rapidly, but the stony cast remains intact. In one small exposure no less than thirteen different kinds of prints were found. These proved the former existence of as many different kinds of reptiles, and yet not even the smallest fragment of a skeleton was found.

Among the commonest of footprints are those of a lizard-like reptile of which one almost complete skeleton has been found. This received the name of **Rhynchosaurus**. This skeleton has so many peculiarities in common with those of a creature living to-day, which is known as the New Zealand lizard, that this is regarded as a survival from Triassic times and may be described as a living fossil (Fig. 148).

It is, however, in the Triassic rocks of South Africa that the

greatest number of fossil reptiles has been found. Some of these,
such as **Pariasaurus**, had heavy, lumbering bodies not unlike those
of the larger amphibia   Their limbs were strong, with the elbows
and knees spread outward and the feet far apart   They must have
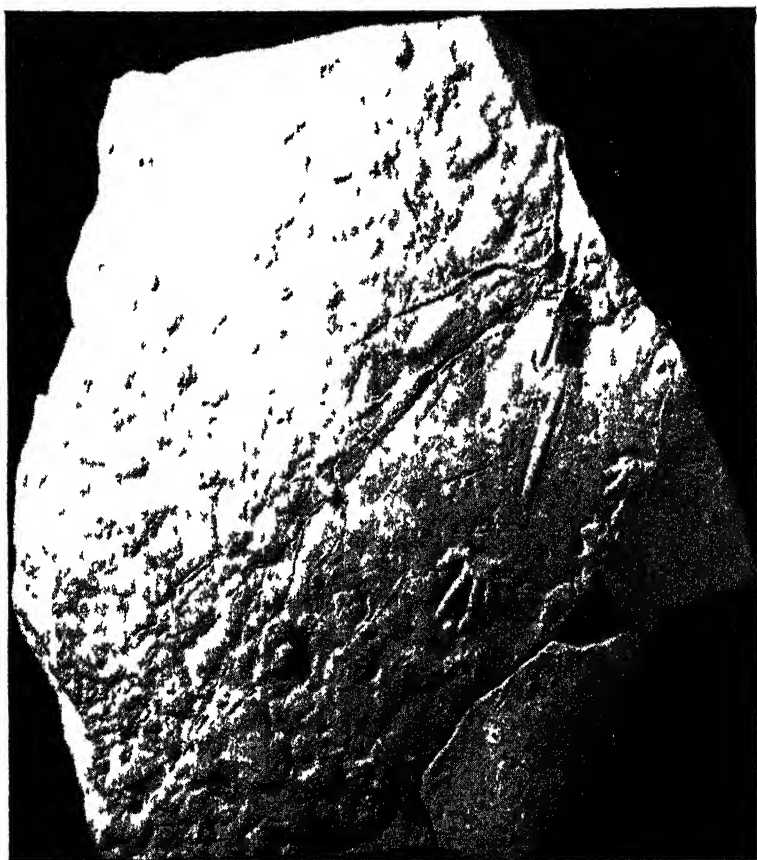
FIG 147   A FOSSIL FOOTPRINT, PERMIAN, WARWICKSHIRE
Casts of footprints made in mud by the left and right feet of a small reptile   The small, rounded
swellings on the surface of the stone are casts of prints made on the original mud by a passing shower
of rain
By courtesy of W Sutcliffe, Esq

moved along with a waddling gait, leaving behind them trails of
left and right footprints widely separated from one another.   At
the other extreme was **Dicynodon** which, as its name implies, had
powerful, tusk-like canine teeth.   The fact that its limbs were
comparatively slender and were straightened out vertically suggests

FIG 148 SOME TRIASSIC REPTILES

Top left, Pariasaurus, *right*, Rhynchosaurus, *bottom left*, Cynognathus

that it was a swiftly moving, possibly predacious, animal. A third
example, **Cynognathus**, may be mentioned. Like others of its
contemporaries, it had a number of features that are characteristic of the furred animals, or **mammals**, which came into prominence at a much later date (Fig. 149). Instead of having simple conical teeth of nearly uniform size, as do most other reptiles, this had teeth varying in size and shape in different parts of the jaw, evidently serving such differing functions as gnawing, piercing, and cutting.

FIG. 149. THE SKULL OF A
MAMMAL-LIKE REPTILE
(GALESAURUS)

As in a mammal the teeth of the gale-saurus are modified in shape and size to serve different functions. .

From Grabau's " A Text-book of Geology,"
Part II

It is considered as very probable that the mammals had their origin among these Triassic reptiles.

It was during the Jurassic period, however, that reptiles attained their heyday. They then infested every nook and cranny of the
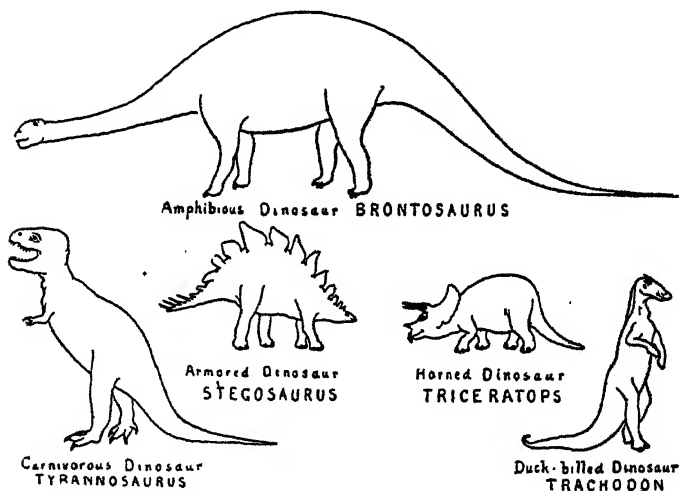
FIG. 150. OUTLINE RESTORATIONS OF DINOSAURS
This shows the relative sizes of different types. The scale is about nineteen feet to
one inch.
From Grabau's " A Text-book of Geology," Part II
(After Matthew, " Dinosaurs ")

landscape, and in addition they invaded both air and water.
Supreme among them were the **Dinosaurs** (Fig. 150). Some
of these had grinding teeth and fed upon the vegetation.

which at that time included many tree-ferns and monkey-puzzle trees (Fig. 151). Such vegetarian kinds usually walked on ' all fours,' and some attained gigantic sizes. From the small head

FIG. 151. THE LAST OF THE DINOSAURS (TRICERATOPS)
Its head was about six feet long.
From a painting by Charles R. Knight, made under the direction of J. B. Hatcher
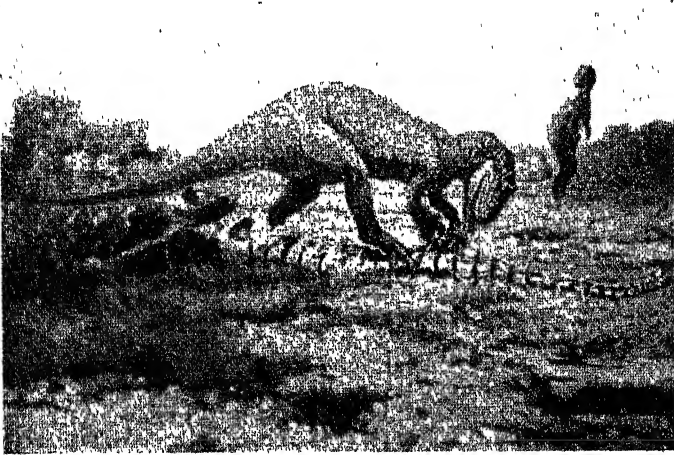
FIG. 152. A RESTORATION OF A CARNIVOROUS DINOSAUR
(ALLOSAURUS)
This reptile had a height of 8 feet 3 inches.
From Grabau's " A Text-book of Geology," Part II
American Museum of Natural History

carried at the tip of a long neck to the end of the equally long tail they sometimes measured as much as 100 feet. There are features about the limb-bones of some of the largest

individuals which suggest that they lived submerged in water. That certainly overcomes the difficulty of understanding how the

FIG. 153. A SMALL, AGILE, CARNIVOROUS DINOSAUR (ORNITHOLESTES)
This dinosaur is holding a primitive bird (*cf.* Fig. 157).
From Grabau's " A Text-book of Geology," Part II

weight of such massive bodies could have been carried. Many of the less bulky dinosaurs walked and ran upon their hind legs. Their front legs were reduced in size, and were no doubt used for
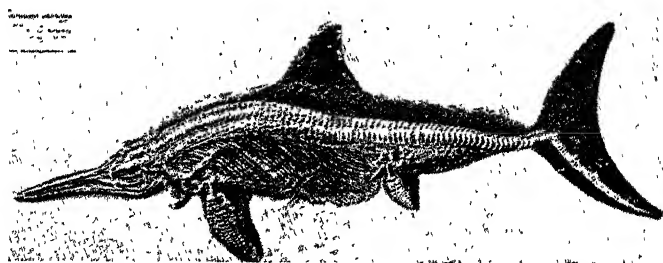
FIG. 154. THE FOSSIL REMAINS OF AN AQUATIC REPTILE
(ICHTHYOSAURUS)
In addition to the skeleton an impression of the skin has been preserved.
From Grabau's " A Text-book of Geology," Part II

pulling the foliage of trees down within reach of the creatures' mouths.

Other dinosaurs were armed with long, piercing teeth and

sharp claws—fierce-looking beasts that preyed upon their more peaceful herbivorous relatives (Fig. 152). At the other extreme of size were small forms, having bird-like heads and feet. They must have looked rather like plucked fowls as they ran here and there searching for the insects upon which they fed (Fig. 153).

Though the dinosaurs were the largest, most varied, and, in

FIG. 155. A RESTORATION OF ICHTHYOSAURUS
It is swimming in the waters of the Jurassic sea.
From Grabau's " A Text-book of Geology," Part II
(American Museum of Natural History)

some respects, the most striking reptiles, there existed other types which should be specially noted. Already, as early as Triassic times, some had become adapted to a life spent in water. Among Jurassic animals these were represented by **Plesiosaurus** and **Ichthyosaurus.** The former attained a degree of adaptation to aquatic life comparable with that of the present-day seal. Like this, it spent most of its time in the water, but sometimes came out and basked upon the beaches. Many features in its anatomy indicate

FIG. 156. THE GIANT FLYING REPTILE (PTERANODON)
Its wings spread as much as twenty-five feet from tip to tip. On the right, small but
well-developed birds are seen in flight over the Cretaceous sea.
From Grabau's " A Text-book of Geology," Part II
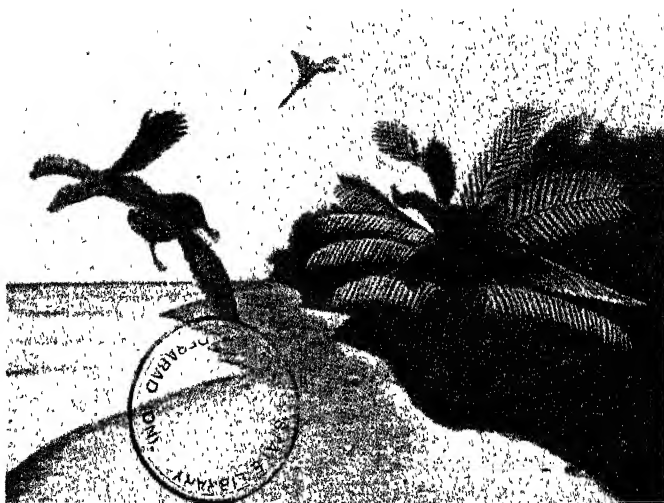
FIG. 157. A RESTORATION OF A PRIMITIVE JURASSIC BIRD
(ARCHÆOPTERYX)
This creature had three fingers with claws on the front margin of its wing. With the
help of these it was able to climb about the bushes and trees.
From Grabau's " A Text-book of Geology," Part II
(After Berry)

clearly that its ancestors were typical land animals. Thus, for instance, its legs had the normal upper and lower portions and feet provided with five toes having the usual number of parts. On the other hand, the total length was much shorter, and the size of the feet much larger, than in a typical walking leg. They had, in fact, become good swimming organs that enabled the animal to move swiftly in pursuit of the fish on which it fed. On the land, however, its movements were merely an awkward scuffle. Ichthyosaurus was a reptile as perfectly adapted for life in the water as a whale (Fig. 154). Its whole body had the stream-line proportions of a fish. Its tail was provided with a fleshy fin at the tip, and was the main organ of propulsion, while the limbs were merely flippers used for steering (Fig. 155).

Some reptiles at the other end of the scale had made great strides towards the conquest of the air. These were the **Pterodactyls,** so called because their ' little ' fingers were as long as their bodies and supported a delicate fold of skin which could be used as a wing (Fig. 156). This received further support from the remainder of both limbs which projected sideways from the body. Like a bat, these creatures could not rise straight into the air from the ground, but had to climb to some high point on the rocks or trees. From thence they dropped and, spreading their wings, could remain flying long enough to make a meal of insects they caught in the air. For this purpose they had a mouth of useful size, often armed with sharp teeth and framed with thin, light bones.

In late Jurassic times a strange-looking creature called **Archæopteryx** appeared upon the scene (Fig. 157). In some respects it resembled the fowl-like dinosaur mentioned above, but was more bird-like than that, especially in the structure of its front limbs. These carried a series of large feathers arranged in a similar manner to those of a bird's wing. Its tail, which was long, was also furnished with a row of feathers on either side. Like the Ptero-dactyl, it also had to climb to some vantage-point before launching out into the air to fly. Unlike that creature, it marked an important milestone in the evolution of birds ; nevertheless, it was still half a reptile. Later stages were passed through with relative rapidity, for, already in Cretaceous times, first-class flying and even diving birds had come into existence.

THE AGE OF MAMMALS

BEFORE the days of canals and railways it was the custom, in some parts of England, for people to roof their houses with thin slabs of stone, known as slates, obtained from local quarries. One such quarry in the Middle Jurassic rocks round Stonesfield, Oxfordshire, became famous among fossil-hunters because, in addition to numerous ordinary fossils, it yielded, for the first time, the jaw-bones of animals belonging to a higher race than the reptiles.
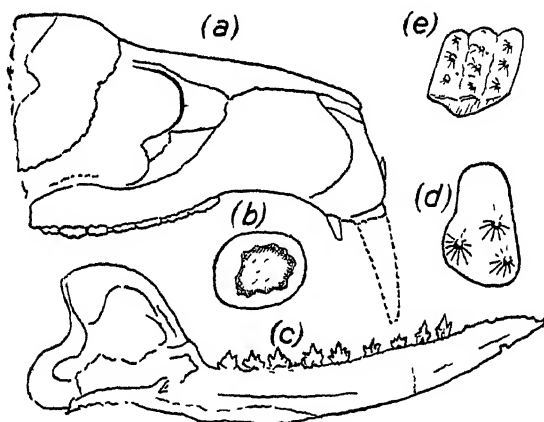
FIG. 158. EARLIEST MAMMALIAN REMAINS
(a) Tritylodon, Trias. S. Africa (after Abel); (b) Tooth of Microestes Rhætic, England; (c) Jaw of Amphitherium Stonesfield Slate, England; (d) Trituberculate tooth; (e) Multituberculate tooth.

These were the remains of tiny mammals no larger than a rat. The front teeth were sharp and conical, like those of a reptile, but the cheek teeth had two or three roots and a crown armed with the same number of sharp cusps or tubercles. Some of these features indicate that they fed on insects. This type of tooth is described as tritubercular, and is regarded as the primitive basis from which many later and much more complicated teeth have evolved.

About the same time a mammalian tooth was found in rocks of yet earlier date—the Rhætic—in Somerset (Fig. 158). These lie just below the Jurassic. This find was, however, eclipsed by the

discovery of a large portion of the skull of a mammal (**Tritylodon**) in the still older Triassic rocks of South Africa. The teeth of this creature had broad crowns armed with many tubercles (multi-tubercular), which were apparently adapted for crushing a vegetable diet. All these finds show that even when reptiles were supreme on the earth genuine mammals already existed. The bones of mammals have also been found in the upper Jurassic rocks of Britain and also in rocks of the same age and in the Cretaceous rocks of North America.
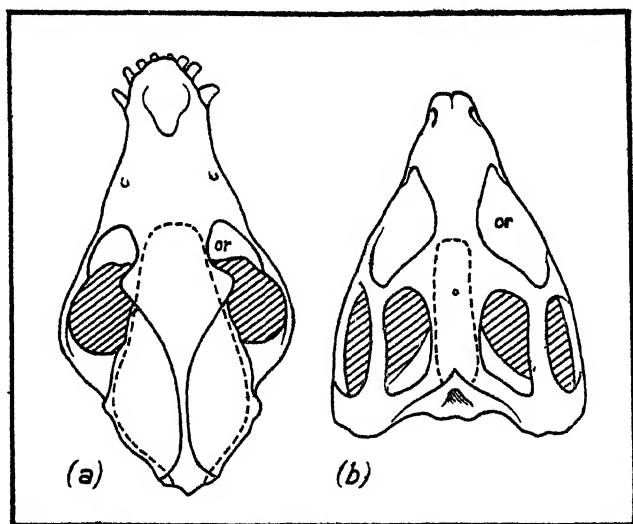
FIG. 159. SKULLS OF MAMMAL AND REPTILE

(a) Dog (mammal); (b) New Zealand lizard (reptile). The dotted line indicates the extent of the brain-case and shows how much smaller relatively the brain is in the reptile than in the mammal (or represents orbit).

During this closing phase of the Mesozoic era the reptilian race declined, and with the opening of the Cainozoic era yielded place to the mammals as the dominating land animals. Among the causes of the late but continued success of these only two need be mentioned. First, their brain cases, and therefore their brains, were much larger in proportion to their bodies than were those of the reptiles (Fig. 159). This fact implies greater alertness and agility. The second was the greater care bestowed upon the young during the earliest stages in development. Our knowledge of this is, of course, based not on the study of fossils, but on that of living forms. Among reptiles these stages were passed through in a large

egg, which was laid upon the ground in a hole or in the sand, where it was left uncared for and unprotected.   Among mammals this habit was abandoned, and the egg was retained within the parent's body where the young, shielded from weather and protected from foes, developed comfortably until it was born.   Even then the parent continued to nurse it until it was able to fend for itself.

While the mammals were gradually rising to pre-eminence the surrounding vegetation did not remain unchanged.   During Jurassic
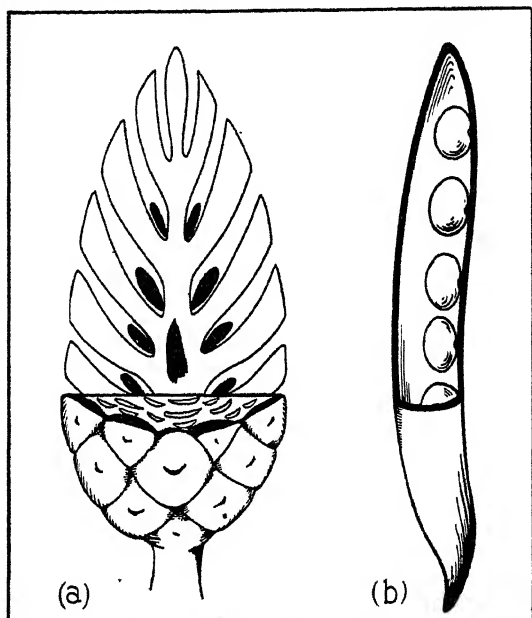
FIG. 160.   THE PROTECTION OF SEEDS
This diagram illustrates the protection of seeds in (a) the gymnosperm with the seeds lying exposed between the scales of the cone ; and in (b) the angiosperm, with the seeds lying enclosed in a pod or capsule.

times seed-bearing plants spread far and wide over the landscape. Many of these were **Gymnosperms**, whose seeds were naked and exposed to the air.   Others, however, advanced an important step farther, and provided additional protection for their seeds by enclosing them in seed-cases (Fig. 160).   These **Angiosperms**, or flowering plants, which to-day dominate the forests and the prairies from the equator to the polar circle, were already represented in Cretaceous times by such familiar types as magnolia, poplar, and birch.   By the middle of Tertiary times those diminutive forms known as grasses and flowers had begun to carpet the earth.

At the beginning of the Tertiary period mammals generally had increased to the size of a sheep, but to an inexpert observer they appear to have differed very little from one another. Space does not permit the description of any of them in detail but, for an appreciation of subsequent changes, a more precise knowledge of the legs and head and particularly the teeth is necessary.

When the animal was at a standstill its body was lifted well above the ground by legs that no longer showed a marked outward bend at the elbows and knees, but extended almost vertically down-

FIG. 161. A RESTORATION OF A PRIMITIVE LIGHT-LIMBED
ODD-TOED HOOFED MAMMAL
This is the *Phenacodus*, which lived at the opening of the Cainozoic (Tertiary) era.
From Grabau's " A Text-book of Geology," Part II
(American Museum of Natural History)

ward to the ground (Fig. 161). Each foot had five digits (toes and fingers), and was planted with its whole length upon the ground. It is evident that these animals could run quite rapidly. The jaws were armed with a moderate number of teeth modified to serve different purposes. In front there were simple, cone-shaped, nibbling teeth, or **incisors**. On either side of these was a single large, sharp, piercing tooth, the **canine**. Behind this was a series of cheek teeth, or **molars**. The hind molars were larger than the front ones, and might be slightly modified either for cutting flesh or for grinding herbage.

With the passage of time these early mammals gave rise to an

amazing variety of forms.   Many of these were quite different
from any with which we are familiar to-day.   Some attained more
than elephantine proportions.   Others again became the fore runners,
if not the actual ancestors, of the animals that surround us to-day.

In one frequently adopted series of changes the length of limb,
and therefore speed in running, was increased by raising the palm
and sole off the ground first, and then the adjoining portions of the

FIG 162A   RESTORATION OF AN ANCESTRAL HORSE
This is the *Eohippus*, which lived at the opening of the Cainozoic
(Tertiary) era   The skull of a modern horse is shown above on the
same scale
From Grabau's " A Text-book of Geology," Part II
(American Museum of Natural History)

digits, until finally only the tips of these rested on the ground.   If
you will place your hand flat upon the table and repeat these move-
ments you will understand the series of changes much better.   You
will also see that while they were proceeding the shorter digits in
turn lost all contact with the ground and became useless ; and thus
all the work fell to the lot of the middle or longest digits.   Among
fossil forms the gradual disappearance of the shorter and the
strengthening of the longer digits can often be followed through
the ages.

Some heavy-bodied, thick-limbed types, including **Cænopus** and **Palæotherium,** which are extinct relatives of the rhinoceros and tapir, came to a halt when the changes had reached a stage at which there were still four digits on the front foot and three on the hind one. Other light-bodied, thin-limbed, swiftly running forms, including **Hyracotherium, Eohippus** (Fig. 162), and **Mesohippus** (Fig. 163), lost all except the middle digit, and thus led up to familiar friends—the horse and donkey, which have one powerful toe in each foot.

FIG 163A   A RESTORATION OF A THREE-TOED HORSE (MESOHIPPUS)

This animal lived in early Cainozoic (Tertiary) times

From Grabau's " A Text-book of Geology," Part II

(American Museum of Natural History)

Parallel with this odd-toed series of animals there came into being an even-toed series (Fig. 164). This also arose from ancestors which had five toes, but at the four-toed stage there was an inner and an outer pair of equal toes. Gradually the outer pairs declined and disappeared, while the inner strengthened and eventually remained alone. In this series also heavy-bodied, clumsy-limbed forms, such as **Anthracotherium,** stopped at the four-toed condition, and are represented to-day by the pig. Lighter-bodied, thin-limbed, swiftly running forms followed a similar course of evolution. **Leptomeryx** did not go beyond the four-toed stage,

N

and to-day numerous animals, such as the deer, antelopes, and cattle, have only two toes on each foot.

All these odd- and even-toed animals have the tips of each toe enclosed in a horny hoof, and are accordingly classed as hoofed animals, or **Ungulates.** In the earlier Ungulates the molars had shallow crowns, with broad, crushing surfaces suited to a diet of soft, succulent vegetation. With the appearance and spread of grasses, these surfaces became specially adapted for grinding rather than crushing. The crown naturally began to wear away
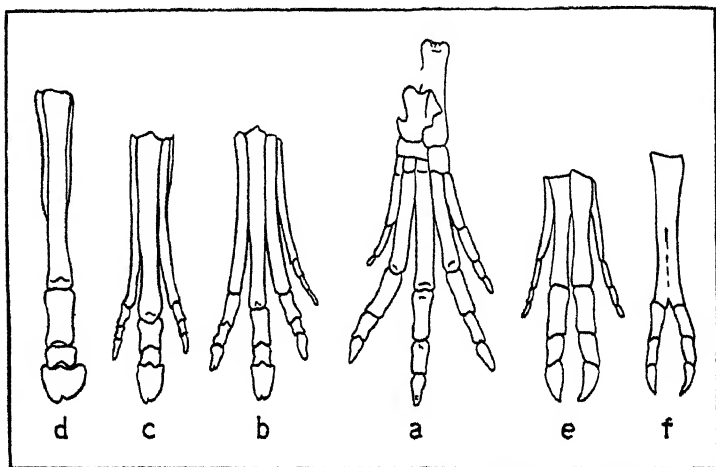
FIG. 164. DEGREES OF SPECIALIZATION IN ODD- AND EVEN-TOED
MAMMALS

(a) Euprotogonia, very early Tertiary; (b) Orohippus, early Tertiary; (c) Mesohippus, a little later than Orohippus; (d) Equus (horse), late Tertiary to present; (e) Sus (pig), late Tertiary to present; (f) Ovis (sheep), present.

more rapidly, but that was offset by a counterbalancing increase in depth (cf. Fig. 171). From this it will be gathered that the Ungulates were, and are—all of them—herbivorous. They became an increasingly important section of the animal population, and to-day they occupy that place in Nature which was occupied in Mesozoic times by the herbivorous dinosaurs.

While those larger groups were producing amazing numbers and variety other smaller groups followed more limited, though not less interesting, lines of change (Fig. 165). One of these started with **Mœritherium,** a creature about the size of a pig. In this series the front end of the lower jaw, together with the upper incisors and nose, steadily increased to a ludicrous length. Suddenly

the lower jaw went into reverse, shortened quickly, and left the other two in possession of the field, to constitute what we now refer to as the tusks and trunk of the elephant. Meanwhile the cheek teeth increased enormously in depth and size (*cf*. Fig. 171).

Another and, of course, quite different line of development was followed by the flesh feeders, or **Carnivora.** In these the limbs underwent comparatively little change, and generally retained four or five toes, equipped with claws on each foot. Earlier carnivores, such as **Cynodictis,** were not unlike the dog in size and proportions, and in the possession of molars with sharp-edged crowns for cutting

FIG. 165. THREE STAGES IN THE EVOLUTION OF THE
ELEPHANTS
From Grabau's " A Text-book of Geology," Part II
(After Osborn, American Museum of Natural History)

flesh. In late Tertiary times some began to specialize on the greater development of the canine and of the middle cheek teeth at the expense of the other ones, which decreased in size, some even disappearing. This was accompanied by that shortening of the snout which gives a distinctive appearance to the cat and its allies, including the extinct sabre-toothed tiger and the existing lions and tigers.

Other groups found a living space in the sea, and reached their culmination in the seal and the whales. Unfortunately, fossil evidence of the stages of change by which they were produced is scanty.

The mode of origin of the bats is also an unsolved mystery.

The parallel between these various mammalian adaptations to life on land, in the sea, and in the air and those already noted among Mesozoic reptiles is very striking.

The coming into existence of new types of trees, which branched freely and often carried an abundant supply of food in the form of
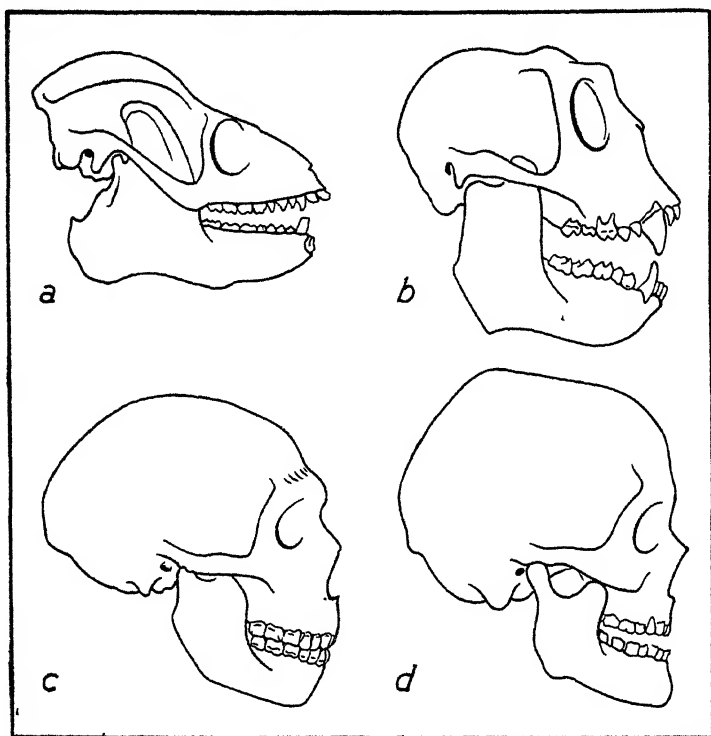
FIG. 166.   SKULLS OF MAMMALS THAT SPECIALIZED IN INCREASING
BRAIN CAPACITY

(a) Adapis, a lemur-like animal (early Tertiary); (b) Mesopithecus, a monkey-like animal (late Tertiary); (c) Neanderthal man, Middle Pleistocene; (d) Magdalenian Man, late Pleistocene.

soft leaves, nuts, and juicy fruits, opened up another sphere for exploitation and even adventure.   Fossils show that in early Tertiary times some small mammals had already taken to a life in the trees. In animals that live upon the ground the legs are bound to the sides of the body in such a way that they can only be moved to and fro and have little, if any, freedom of movement in other directions. But climbing the trunks of trees, and running along branches tilted at varying angles, involved frequent changes of attitude—stretching

forth to reach fruit, balancing on thin boughs, and snatching at them during a fall. All these daily, even hourly, incidents called not only for complete freedom and suppleness of limbs, hands, and feet, but for quick vision and accurate 'gauging of distances. It is not surprising, therefore, that the outstanding line of specialization in this series of animals was a progressive increase in size of the organ which controls all movements : the brain. This was clearly reflected in the shape and size of the brain-case (Fig. 166). In early Tertiary times the series included creatures like **Adapis** which showed that a condition comparable with that in the lemur had been reached. Before the middle Tertiary true monkeys, and then man-like apes, had appeared. In the late Tertiary some of the latter exhibited a size of brain relatively larger than that of any living ape, but smaller than that of any known human being. These are, as it were, the first streaks of the dawn which marked the coming of man.

THE COMING OF MAN

THUNDERSTONES ': that is what they were called. They were roughly shaped, sharply triangular stones, and for centuries people believed they were thunderbolts (Fig. 167). At the end of the sixteenth century, when the modern scientific way of looking at Nature was dawning, Michael Mercati claimed that these stones had been shaped by man in ancient times. It was not, however, until the middle of the nineteenth century that enough evidence had been collected to convince a number of scientific men that Mercati was right. Interest was now aroused, and more workers joined in the search for further clues. Since then multitudes of these ancient implements, made from flint and other stones, have been found, first of all in England and Western Europe, but later in many different parts of the world. To-day no one doubts their human workmanship.

FIG. 167. AN EARLY OLD STONE AGE (PALÆOLITHIC) FLINT IMPLEMENT

This is from gravels of the Ice Age (Pleistocene) in the Valley of the Somme, France. (a) Shows the face view, and (b) the edgewise view.

From Grabau's " A Text-book of Geology,"
Part II
(After Lyell's " The Antiquity of Man ")

The most fruitful hunting-grounds have been the gravels of river-terraces and the deposits in the floors of caves. The searchers take the utmost care as they dig. As each layer is being removed they examine almost every spoonful of earth with great diligence, and keep a very precise record of the exact position in which every find, be it implement, flake, or bone, occurs. The outcome of all this patient toil has been not merely the collecting of tons of implements but the discovery that with the passage of time there has been progress in workmanship and in the variety of tools

and material used.   All this has provided proof of their human workmanship, and reflected man's growing skill and intelligence.

At the outset man did no more than pick up stones of suitable size for use either as a missile or a weapon.   To-day a searcher may find one of these, but he cannot be certain that it was actually

FIG. 168. A RESTORATION OF EARLY OLD STONE AGE MAN
(NEANDERTHAL MAN)
This is from a painting by C. R. Knight, under direction of H. F. Osborn.
From Grabau's " A Text-book of Geology," Part II
(American Museum of Natural History)

used by early man. A large number of such stones has been found showing signs of chipping, but comparatively few workers accept them as genuine.   Other stones, less crudely shaped, show chipping that is more systematic than that done by any known natural process.   These are accepted as dating from the dawn of human skill and are called **Eoliths**.

The next more advanced type of implement is known as the

Palæolith. The places where early man actually manufactured these have sometimes been found. From one such site an imperfect implement and most of the flakes that were knocked off the flint in order to make it were found. With infinite patience these were all fitted together again, and thus the original lump of flint was reconstructed. Though at first the cores of such lumps were most highly valued for use as implements, quite often chips of suitable size and shape were touched up along the edges, and were used for such purposes as scraping the inner surface of skins.

Later on man developed such skill in working flint that he could produce flakes of just the size and shape he wanted. He then became equipped with tools with which he could carve bone, out of which
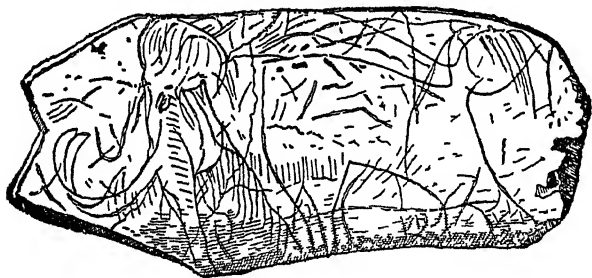
FIG 169   A DRAWING OF THE MAMMOTH ON IVORY
This was made by late Old Stone Age man (Magdelenian man)
From Grabau s " A Text-book of Geology," Part II
(After Lucas, from Matthew)

he made needles, javelin points, and a number of other useful implements. These later products of his skill are also called **Palæoliths.**

Palæolithic man : that is the name given to this highly intelligent being who could do so much with so little. Naturally fossil remains of the man himself are much rarer than his tools, but enough more or less complete skeletons have been found to give us an accurate picture of his personal appearance (Fig. 168). These show that early and late Palæolithic men were remarkably different from one another. The former stood little more than five feet high and was short and stocky. His face projected in front of the brain-case, which was wide and flattened, and had a sharply receding forehead. His arms were long, his feet big, and his short legs bent slightly at the knees. Late Old Stone Age man, on the other hand, was remarkably tall, often more than six feet high ;

and his head, face, and brain-case were distinctly modern. The great length of his legs, together with other features, shows that he was a swift runner. He possessed great artistic skill (Fig. 169), both in carving bone and making drawings and paintings of the animals he hunted on pieces of bone or on the walls of the caves in which he dwelt (*cf.* Fig. 168). Some of these are particularly fascinating, because they give us pictures, drawn from life, of animals that have been extinct for thousands of years (Fig. 170).
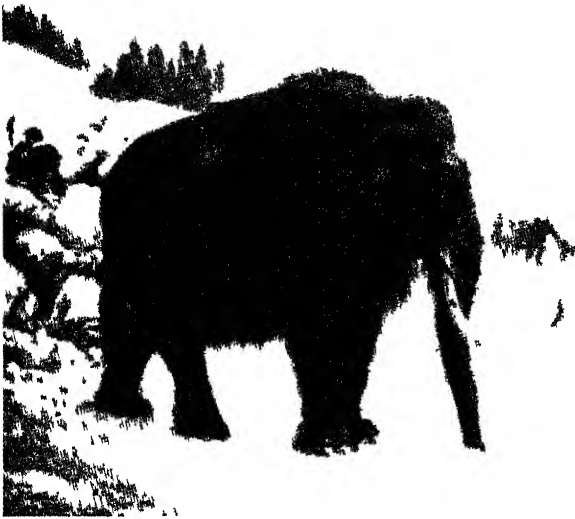
FIG 170   THE WOOLLY MAMMOTH

This is a restoration based on the study of frozen carcases found in tundra regions
Compare this with contemporaneous drawings shown in Fig 169
From Grabau's " A Text-book of Geology," Part II
(American Museum of Natural History)

The period ranging from the time when some more than usually man-like ape threw stones, or shaped them roughly to his needs, to the time when men of almost modern type existed, capable of carving and drawing so exquisitely, is variously estimated as having lasted from a quarter to as much as one million years. During this period, which is known as the **Pleistocene,** the climate of Northwest Europe and Canada experienced a series of intensely cold spells, separated by long intervals of normal or even warm temperatures.

The oncoming of a cold spell was marked by a gradual lowering of the average temperature. At first, only the uplands became covered with snow and icefields. In due time these extended down

to the lowlands, and gradually filled up the broad, shallow basins of the Baltic Sea and Hudson Bay, and spread yet farther on to the plains of Russia and the upper reaches of the Mississippi Basin. Eventually this sequence of events went into reverse. The climate became progressively milder and warmer. The icefields withdrew from the lowlands and shrank to negligible fragments on the highlands of Scandinavia and among the mountains of Canada. The

FIG. 171. THE TEETH OF MAN, HORSE, AND MAMMOTH

These give an idea of the relative sizes of the animals themselves. The deep crowns of the two latter are an adaptation to the need for grinding their dry vegetable food

By courtesy of W Sutcliffe, Esq.

whole of such a sequence of events is called a **Cycle of Glaciation**, and, according to reasonable estimates, lasted about 20,000 years.

In Western Europe one set of cycles separated by a warmer interval took place in the early Pleistocene, and another in the late. Between the two sets—known respectively as the early, or older, and the late, or younger, glaciations—came a very long, genial interval. The older included the severest of all the glaciations, when the ice-sheets covered the British Isles as far south as the Severn Estuary and the northern margin of the Thames Valley (Fig. 172). During the younger glaciations ice coming from the

continent across the North Sea merely lapped on to the fringes of
the East Coast from Yorkshire to Norfolk, while purely British ice
failed to reach the Midlands. Northern and Central Wales had
icefields of their own, and some ice from the Irish Sea pushed its
way over the plains of Cheshire and Shropshire (Fig. 173).
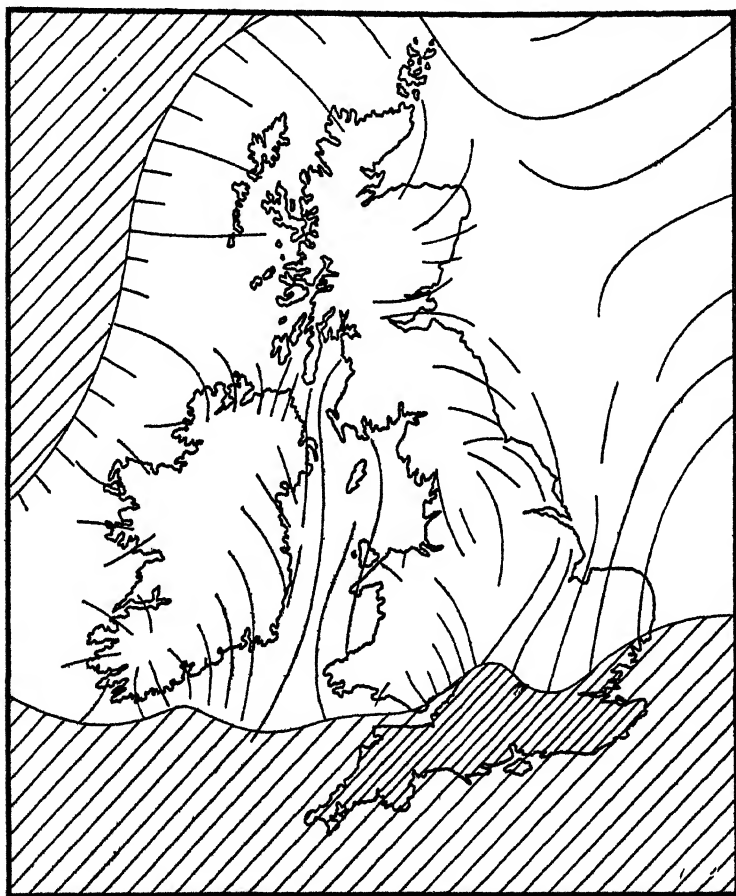
FIG. 172. MAP OF THE BRITISH AREA IN THE EARLY ICE AGE
The wavy lines show the extent of the ice sheet and the general direction of flow of the ice.

Eolithic man lived in the early Pleistocene. Early Palæolithic
man arose during the older glaciations, lived out in the open on the
river plains during the long, warm interval, and found a refuge in
caves until the middle of the later glaciations. Late Palæolithic
man lived during the closing phases of these glaciations.

Each time that climates of arctic severity crept southward over North-west Europe and North America the other climatic belts likewise shifted in the same direction. Then it was that the areas round the Black Sea and in North Africa, which to-day are semi-desert or desert, experienced abundant rainfall, and extensive
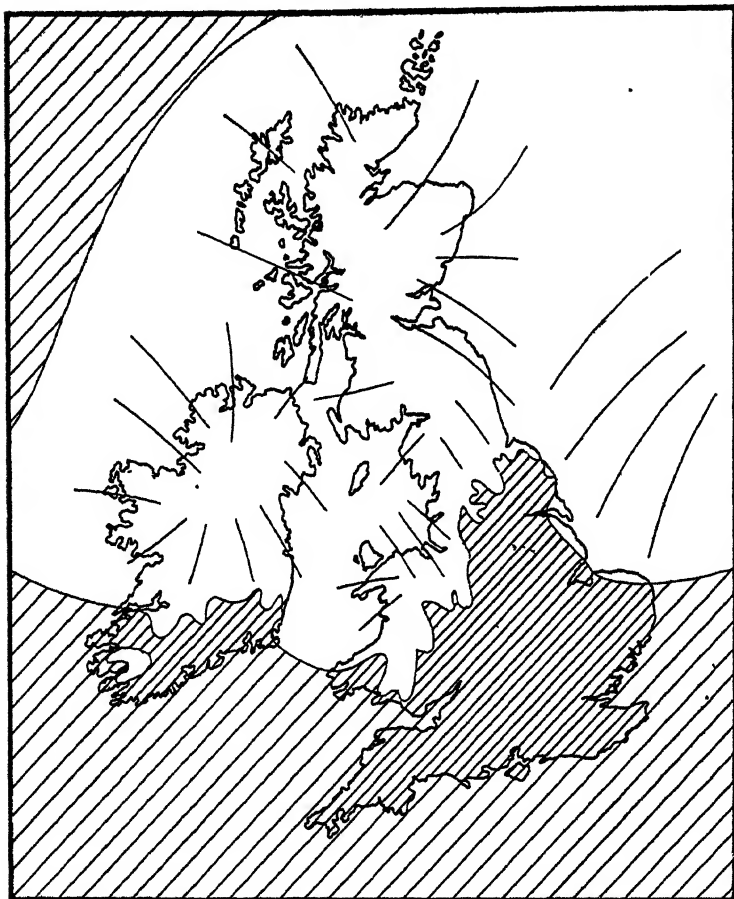
FIG 173. MAP OF THE BRITISH AREA IN THE LATE ICE AGE

stretches of low ground became covered with sheets of shallow water. Such conditions are described as pluvial, and the times during which they prevailed are called **pluvial periods**. It was in these areas, and in others where the climate was still more genial, that Eolithic and Palæolithic man flourished. Even the Sahara has yielded numerous Palæoliths. Those whose workmanship is found

in Western Europe were emigrants possibly in search of new hunting-grounds.

Geologically the Pleistocene was but a brief period. The changes produced during it upon the landscape were like the final touches made by an artist to his pictures—they were slight, but were important in their effects. In the lowlands boulder clay was spread like a thin veneer over large areas, and completely altered the character of the soil. In the highlands and mountains narrow valleys were widened out into broad passes, lake basins established, and spurs truncated. On the sky-line the round-topped mountains of the Tertiary epoch were chiselled by the intense frosts into sharp edges and pointed peaks. Meanwhile man progressed from being little more than a beast of the field to being only a little lower than the angels.

YESTERDAY AND TO-DAY

BEES. Honey. Those two words go together. But if you have watched a bee pushing its way into a flower and then coming out again you will have seen that its furry back was covered with yellow dust. If you caught the bee and brushed some of this pollen dust on to a glass slip, then examined it under a microscope, you would find that each minute grain of pollen was round, likè a tiny ball with a prettily decorated surface. But the grains are not all exactly alike. Show them to an expert and you would hear him say, " This grain came from a foxglove, that from a sweet pea, and the third from an antirrhinum."

When the wind blows over the landscape it also picks up pollen from all kinds of flowers and trees, and carries it far afield. Sooner or later the pollen falls to the ground. If it happens to fall on a wet swamp or bog it becomes entangled in the remains of mosses and other plants that live and die on the spot and form peat. These remains may rot, but the pollen grains, because they are cased in the most resistant of vegetable substance, retain their form and decoration. Here and there, in fenland, in alluvial plains, round lake margins, on lofty moorlands, beds of peat have often been formed four, eight, even ten, feet thick. This accumulation of vegetable waste must have taken a long time to form. Here, once more, the bottom layer was formed first and the top last. In each layer the pollen grains furnish a record of the flowers and trees that decked the landscape for miles around at the time when it was being made. By taking ten or twenty samples of peat from as many different layers in a thick bed of peat, and identifying and counting the pollen grains in each, scientific workers have been able to reconstruct in remarkable detail the changes in the flora, and even in the climate, which took place during the time of formation of the peat (Fig. 174). This has been done for a number of cases, and, though the task is a very laborious one, it has proved well worth while.

Whenever, during the Pleistocene, a cycle of glaciation set in and the climate became progressively colder, most of the vegetation migrated southward, along with the migrating belt of warmer conditions. The British Isles thus became almost depleted of trees

and flowers. This, then, is the background of the story told by the peat. When it opened the ice-sheet had begun to shrink, and the countryside it vacated was like the Arctic tundra—dotted here and there with dwarf birch and Arctic willow. Then came the hazel-bushes, which spread rapidly and grew in great profusion every-where. Next came the pine-trees, and they covered the British landscape with forests. As the climate became more genial they
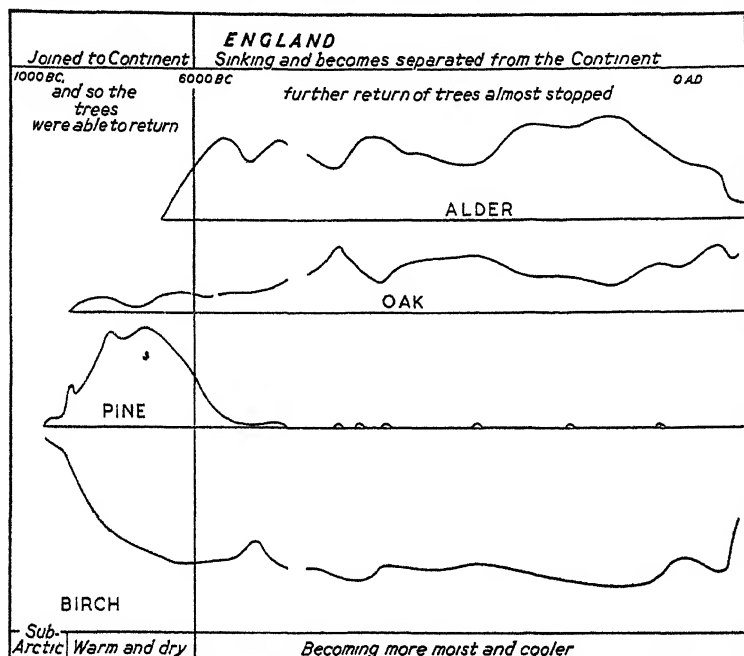
FIG. 174. THE STORY OF BRITISH FORESTS
The above graphs are the story of British Forests as told by pollen grains in peat from Chatmoss.
Based on Erdtman

were followed by the oak. Pine-trees still grew, but the oaks became supreme. These pioneers were later joined by the ash, alder, elm, and other trees of the deciduous forest. Thus the present constitution of our British vegetation was established.

The coming of the deciduous forest was accompanied by the migration of people from the east who kept flocks and herds, grew corn, made pottery, and wove cloth. Though their implements were still made of stone, and were often chipped with exquisite skill, many were shaped by grinding them upon other stones, and thus had polished instead of chipped surfaces. These people are

spoken of as belonging to the **Neolithic,** or New Stone Age,
(Fig. 175).

At the opening of this age, some time before 2000 B.C., the
North Sea and English Channel were non-existent (Fig. 176), and

a   b
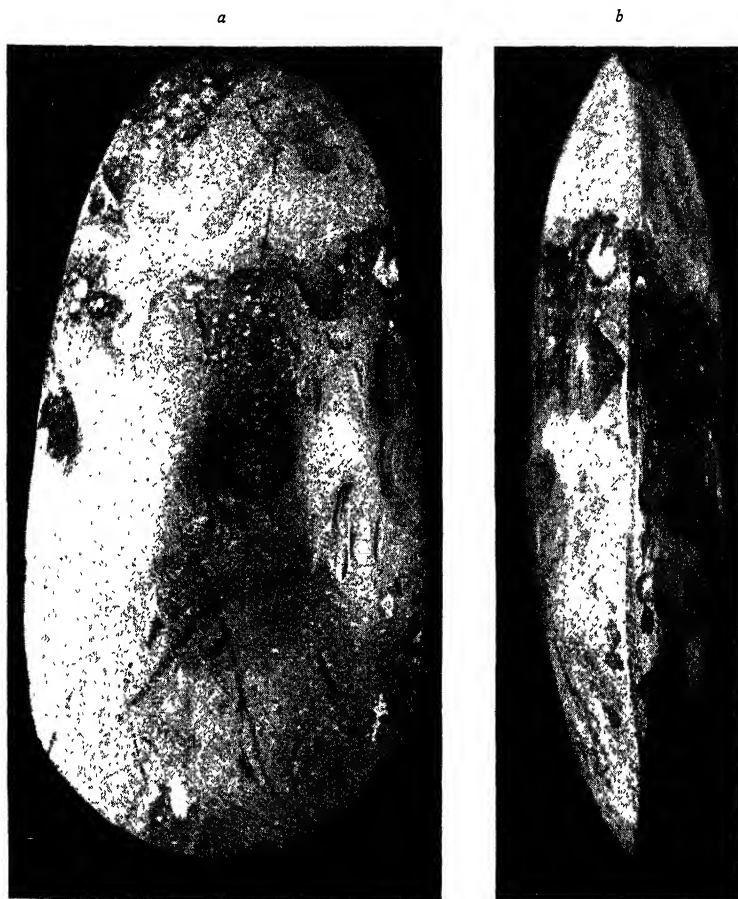
FIG. 175. A NEOLITHIC IMPLEMENT, COLLINGHAM, LINCOLNSHIRE
Shown above are (a) the face view and (b) the side view. Note the traces of chipping which reduced
the flint to a suitable size and shape before it was ground to its present form and then polished.
By courtesy of W. Sutcliffe, Esq.

Britain occupied a broad, lobe-shaped peninsula projecting from
Western Europe. From that time until now this region has, on the
whole, been sinking slowly, though there have been temporary
stoppages or even slight recoveries. During the New Stone Age
this movement progressed so far that the North Sea and English

Channel areas became submerged, and Britain was finally isolated from the continent.

Though the general outlines of the British Isles have remained practically unchanged, many details of the coastline, especially in the South-east of England, have been strikingly modified. Thus,
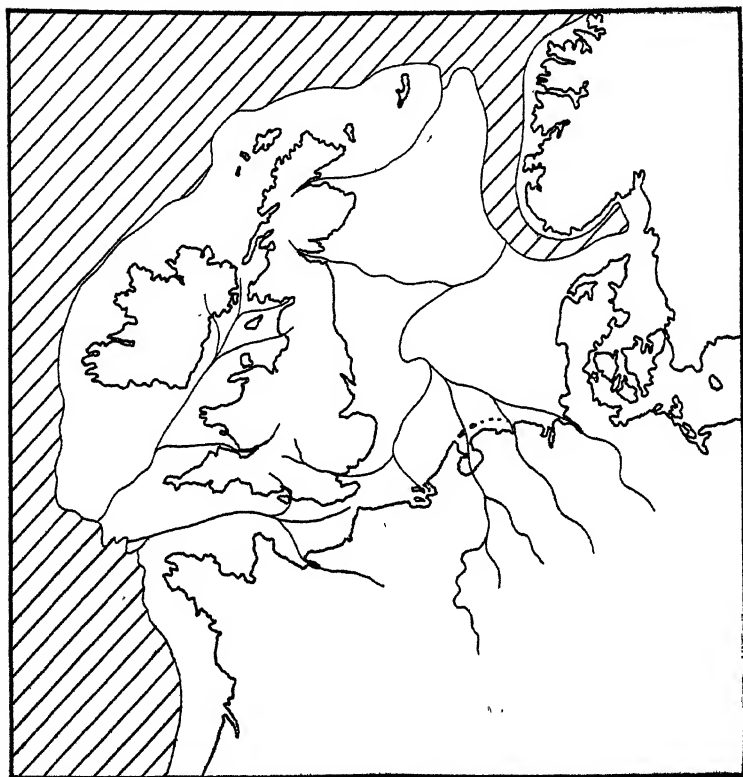
Fig. 176. MAP OF THE BRITISH AREA AFTER THE ICE AGE
This map shows the area before it had become separated from the Continent.

for example, in consequence of the main neolithic sinking (Fig. 177), the Wash widened out into a small semi-enclosed sea, covering the whole of the area now called the Fen country. The same was true also for the Carrlands of South Yorkshire and North Lincolnshire. The deep narrow valleys of Devon, Cornwall, and Pembrokeshire were also drowned (Fig. 178. *Cf.* Fig. 109). Mud brought down by the rivers, and silts by the incoming tides, have gradually filled up these large expanses of sea-water (Fig. 179). On the other hand, the coasts

o

of Norfolk and Suffolk were deeply indented with long
separated by projecting promontories.   Here again th
muds and tidal silts filled up the inlets (Fig. 180).   Mear
waves of the sea cut the promontories away and gave to 1
line its present simple outline.

During the early part of the Roman occupation of B1
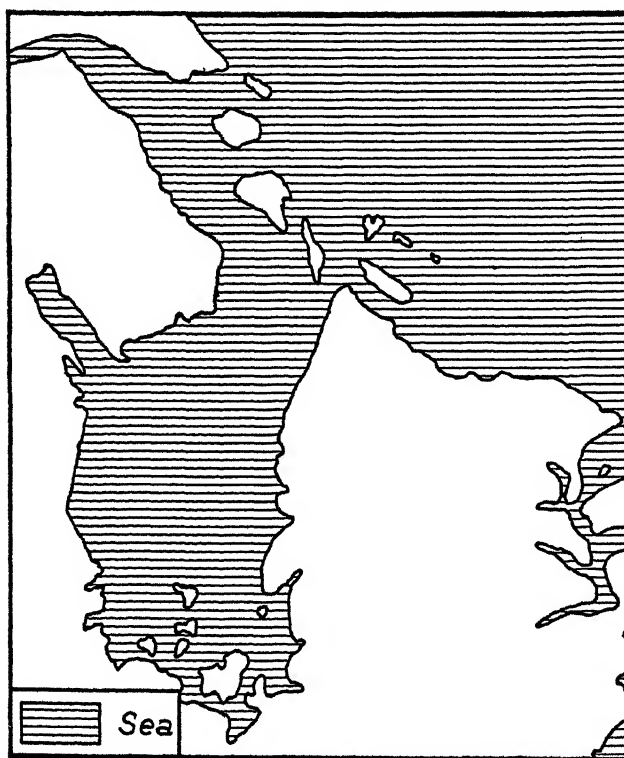
FIG. 177. MAP SHOWING THE COAST-LINE OF LINCOLNSHIR
EAST ANGLIA

This map represents the coast-line after the submergence which took ·
during the New Stone Age

the five centuries which preceded it, sinking ceased an
uplift took place.   The Fenland became sufficiently rai
sea-level to be occupied and extensively cultivated by
and their Roman conquerors.   In the last century of t'
occupation, however, sinking was renewed, and these
lands became swamped under fen and sea, and were cha
watery waste, haunted by wild fowl until medieval times.

FIG 178   THE YEALM INLET, DEVONSHIRE

As the result of the general lowering in level of the land since the middle of the New Stone Age
the lower reaches of this and other valleys have been submerged and converted into inlets   As
the waters of the rivers and of the sea here are very clean these inlets have not become silted up
like those of the Fast Coast

Photo H H Swinnerton

FIG 179   FRIESTON SHORE, ON THE NORTH SIDE OF THE WASH

The sea at high spring tide is creeping in slowly over the vast area of salt marsh. Twenty minutes
later it completely covered the whole area   During the slack water at high tide marine silt settles
out and is left behind when the tide recedes. In this way the level of the salt marsh is being gradually
raised, until in due time it will become land.

Photo H. H. Swinnerton

For like reasons the lower reaches of many English rivers became diminished in fall towards the sea, and have been subjected, in consequence, to more frequent flooding. The muds carried by the
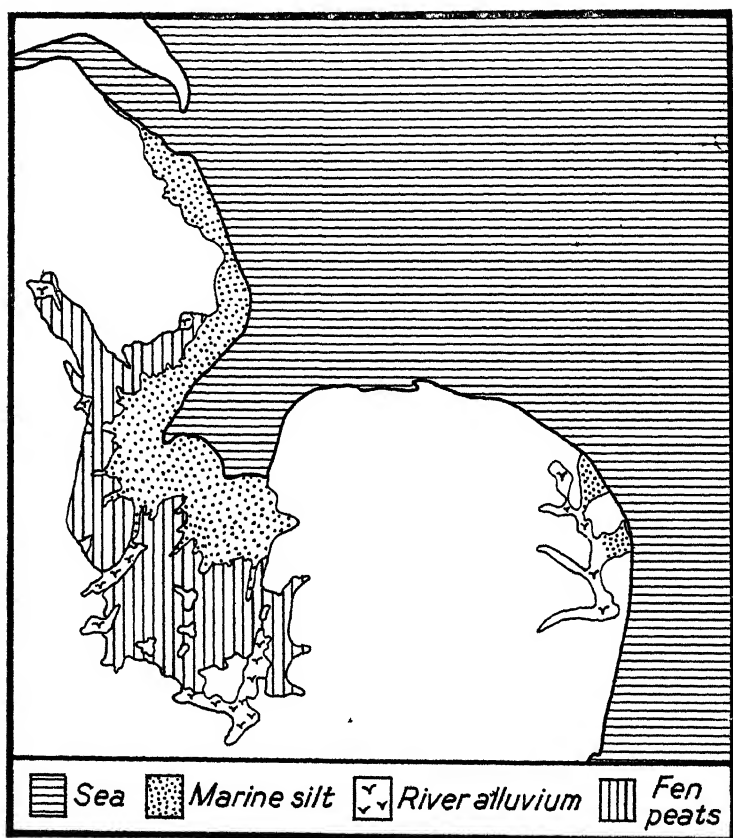
FIG. 180. MAP SHOWING THE COAST-LINE OF LINCOLNSHIRE AND
EAST ANGLIA TO-DAY

This should be compared with Fig. 177 in order to see how the New Stone Age coast-line has been modified on the one hand as the result of erosion of the promontories by the sea, and on the other of the filling up of the inlets by marine silts, river muds, and peat.

flood-waters have been deposited in thin sheets, and have given the final touches to the alluvial plains.

In the New Stone Age forests covered about 80 per cent. of our countryside. The depredations of man have reduced this to 4 per cent., and have resulted, no doubt, in a more rapid run off of rain water and an increase in the rate of erosion by streams. In modern times man, with his great mechanical devices, has done

work comparable in its effects with that done by some natural agencies. Surface sinking due to mining has upset local drainage and turned smiling vales into gloomy wastes.

Nature waits patiently for a cessation of man's activities, when she will return and convert his ugly tip-heaps and gravel-pits into things of beauty. Taken as a whole, however, they are but tiny blots upon a landscape whose harmonious beauty has been enriched by contributions from all the ages : the sunshine and the air from the condensing nebula ; gneiss, schist, slate, conglomerate, lime-stone from bygone mountains and seas ; algæ, mosses, ferns, monkey-puzzles, palms, and oaks—relics from ages when each type in its turn was supreme ; dragon-flies, snails, lizards, kangaroos, butterflies, pigs, cattle, apes, each in their own way adding some points of interest, some unique splashes of beauty to this complex world.

Man is indeed the heir of all the ages. The more he realizes this the more anxious will he become to refrain from wanton destruction, and to make his own contribution worthy of these survivals from the past.

APPENDIX

GEOLOGICAL TERMS AND THEIR MEANINGS

THE geologist looks at Nature so carefully that he sees many things other people have never seen, and for which they have no names. He must therefore create many new names and terms. Sometimes he builds these up from words of other languages, particularly Greek and Latin. At other times he adopts or modifies words already in use, or incorporates the names of people or places. The following list contains the component parts of most terms used in this book. With its help the reader may reconstruct the words and discover their meanings.

-aceous. Lat. *aceus* = like.
aletho. Gr. *alethos* = true.
amphi. Gr. *amphi* = both.
a, an. Gr. *a* = not.
angio. Gr. *angeios* = vessel.
anthrac. Gr. *anthrax* = coal.
anti. Gr. *anti* = opposite.
arachn. Gr. *arachne* = spider.
archæ. Gr. *archi* = beginning.
aren. Lat. *arena* = sand.
argilla. Lat. *argilla* = clay.
arthro. Gr. *arthron* = joint.
aspis. Gr. *aspis* = shield.
bary. Gr. *barys* = heavy.
batho. Gr. *bathos* = depth.
-bia. Gr. *bios* = life.
blende. Ger. *blenden* = to deceive.
brachi. Gr. *brachion* = arm.
breccia. Ital. *breccia* = a crumb.
caino, cæno, cene. Gr. *kainos* = new, recent.
dactyl. Gr. *dactylos* = finger.
dendron. Gr. *dendron* = tree.
di. Gr. *di, dis* = twice.
dino. Gr. *deinos* = terrible.
ella. A diminutive ending.
eo. Gr. *eos* = dawn.
eury. Gr. *eurus* = broad.
fels. Ger. *fels* = rock.
fer. Lat. *fero* = I carry.
ferro. Lat. *ferrum* = iron.
fluor. Lat. *fluo* = I flow.
gabbro. An Italian name.
galena. Gr. *galene* = calm.
geo. Gr. *geios* = belonging to the earth.
glabella. Lat. *glaber* = hairless.
glauco. Gr. *glaukos* = bluish-green.
gnath. Gr. *gnathos* = jaw.

gneiss. German miner's term.
gonia. Gr. *gonia* = corner.
graph. Gr. *grapho* = I write.
grapt. Gr. *graptos* = painted.
gryphæa. Gr. *gryps* = a griffin.
gymno. Gr. *gymnos* = naked.
hæma. Gr. *hæmo* = blood.
hemi. Gr. *hemi* = half.
hippus. Gr. *hippos* = a horse.
hyracho. Gr. *hyrax* = a coney.
ichthy. Gr. *ichthyos* = fish.
-id. Gr. *eidos* = form.
igne. Lat. *ignis* = fire.
-ina, -ine. Lat. *inus* = pertaining to.
-ite. Gr. *ites* = belonging to.
·jur. Jura mountains.
kyanite. Gr. *kuanos* = dark blue.
lacco. Gr. *laccos* = cistern.
lepido. Gr. *lepidos* = scale.
lepto. Gr. *leptos* = slender.
-lith. Gr. *lithos* = stone.
-logy. Gr. *logos* = discourse.
magnes. Magnesia, a city in Asia Minor.
malach. Gr. *malache* = mallow.
mammal. Gr. *mamma* = breast.
meryx. Gr. *merukazo* = chew the cud.
meso. Gr. *meso* = middle.
meta. Gr. *meta,* signifying change.
mico. Lat. *mico* = glisten.
micro. Gr. *micros* = little.
morph. Gr. *morpha* = form.
mylon. Gr. *mylon* = mill.
neo. Gr. *neos* = new.
odon. Gr. *odontos* = tooth.
olivine. Lat. *oliva* = olive.
oo. Gr. *oon* = egg.
osteo. Gr. *osteo* = bone.

palæo. Gr. *palaios* = ancient.
pelago. Gr. *pelagos* = sea.
pene. Lat. *pene* = almost.
per. Lat. *per* = through.
Permian. *Perm,* a Russian province.
physio. Gr. *phusis* = nature.
placer. Span. *placer* = deposit.
pleisto. Gr. *pleistos* = most.
plesio. Gr. *plesios* = near to.
pod. Gr. *podos* = foot.
pre-. Lat. *præ* = beforehand.
proto. Gr. *protos* = first.
pseudo. Gr. *pseudo* = false.
ptero. Gr. *pteron* = wing.
pterygii. Gr. *pterygos* = wing, fin.
rhyncho. Gr. *rhynchos* = beak.
saur. Gr. *sauros* = reptile.
schist. Gr. *schizo* = I split.
scoriæ. Gr. *scoria* = dross.
sigill. Gr. *sigillum* = seal.
silicon. Gr. *silex* = flint.

sillimanite. Silliman was an American chemist.
sperm. Gr. *sperma* = seed.
stauro. Gr. *stauros* = cross.
stego. Gr. *stege* = roof.
syene. An Egyptian town.
syn. Gr. *sun* = together.
terebrat. Lat. *terebratus* = perforated.
tertiary. Lat. *tertiarius* = containing a third.
Tethys. A Greek sea deity.
therium. Gr. *therium* = animal.
thorax. Gr. *thorax* = chest.
tourmaline. Cingalese turmali.
tri. Gr. *treis* = three.
-ula. A diminutive ending.
ung. Lat. *unguis* = claw, hoof.
vertebrate. Lat. *vertebratus* = jointed.
vious. Lat. *via* = way.
vore. Lat. *voro* = I devour.
zoic. Gr. *zoe* = life.

NOTES

Ammonite. So called because of the similarity of the shell to the horns on a statue of Jupiter Ammon.
Armorican. Armorica was the Roman name for Brittany.
Bauxite. First found at Baux, near Arles, France.
Biotite. After the French mineralogist Biot.
Blende. Looks like lead ore but produces no lead.
Chiasto. Marked with a cross like the Greek letter ' chi.'
Galena. Supposed to have a calming effect in cases of violent disease.
Garnet. Possibly derived from the Latin *granatum* = pomegranate. The colour of garnet is like that of the pulp of this fruit.
Hercynian. Refers to the name of certain wooded mountain areas in Germany, especially that of the Erzegebirge.
Kaolin. From the Chinese word ' Kauling ' (= high ridge). This was the name of a hill where china clay was mined.
Limonite. Often occurs as bog-iron ore or meadow ore. Greek *leimon* = a meadow.
Mœri. From the Greek *Mœris* = the name of an artificial lake in the Fayum area, Egypt, where the fossil remains of ancestral elephants were found.
Ordovician. From that part of Wales inhabited by the Celtic tribe the Ordovices.
Silurian. From that part of Wales inhabited by the Celtic tribe the Silures.
Variscan. From the Latin name of Voigtland, a part of Germany.

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(NOTE. References to illustrations, diagrams, or maps only are shown in heavy type.)